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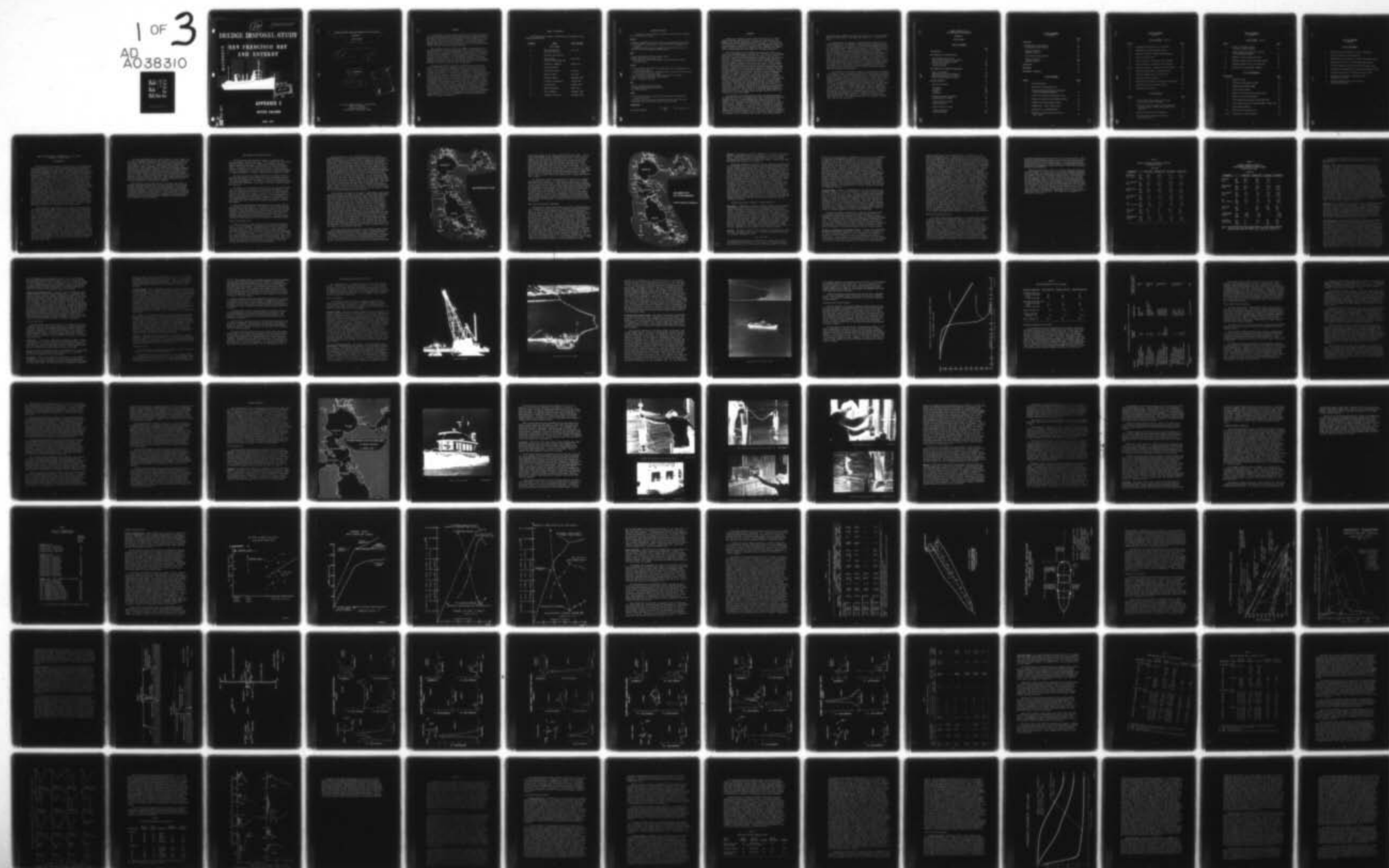

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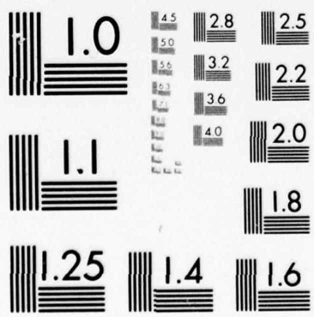

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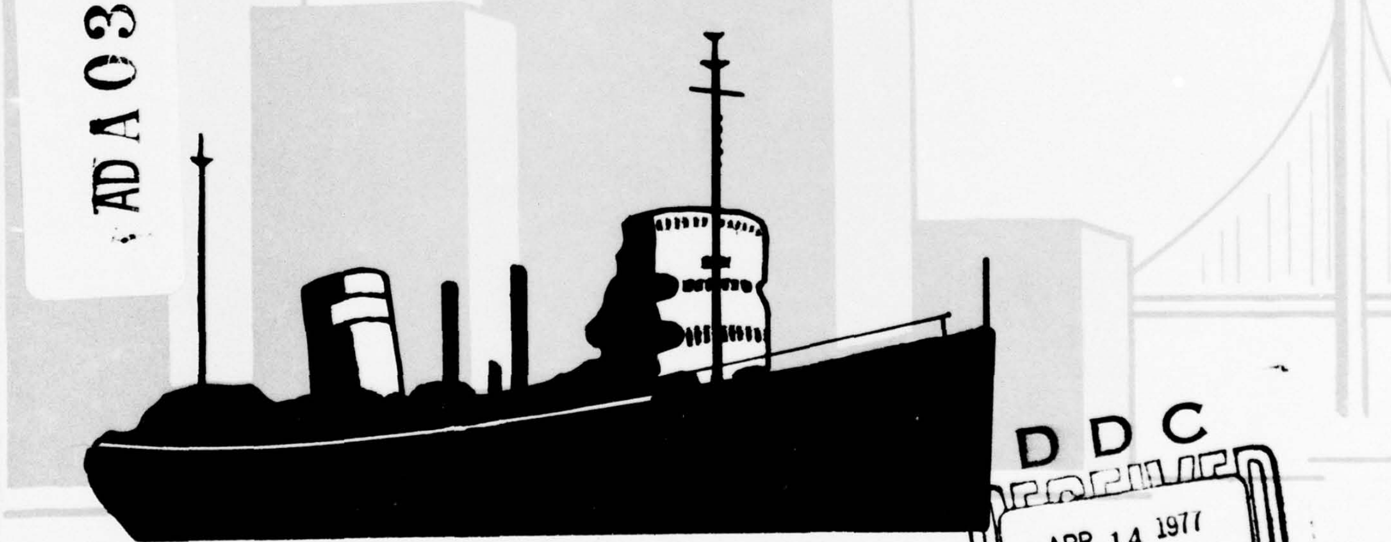
DREDGE DISPOSAL STUDY

SAN FRANCISCO BAY AND ESTUARY



APPENDIX C

WATER COLUMN

APRIL 1976

6 DREDGE DISPOSAL STUDY, SAN FRANCISCO BAY AND ESTUARY.

APPENDIX C

WATER COLUMN

9 Final rept.

11 APRIL 1976

12 180p.

U.S. Army Engineer District, San Francisco
Corps of Engineers
100 McAllister Street
San Francisco, California 94102

FOREWORD

In April 1972, the San Francisco District of the United States Army Corps of Engineers initiated a three million dollar study to quantify the impact of dredging and dredged material disposal operations on the San Francisco Bay and Estuarine environment. The study has generated factual data, based on field and laboratory studies needed for the Federal, State and local regulatory agencies to evaluate present dredging policies and alternative disposal methods.

The study was set up to isolate the questions regarding the environmental impact of dredging operations and to provide answers at the earliest date. The study was organized to investigate (a) the factors associated with dredging and the present system of aquatic disposal in the Bay, (b) the condition of the pollutants (biogeochemical), (c) alternative disposal methods, and (d) dredging technology. The study elements were intended first, to identify the problems associated with dredging and disposal operations and, second, to address the identified problems in terms of mitigation and/or enhancement.

Dredging and disposal operations influence water quality principally by increasing the suspended solids concentration in the water column. These resuspended sediments can effect water quality by increasing the turbidity level, exerting a demand for oxygen and/or increasing the nutrient or contaminant concentration of the water mass via release from the sediment. Water Column, Appendix C, investigated the first and second effects and described each phenomena quantitatively as to magnitude and duration under specific dredging and disposal conditions in San Francisco Bay. The third effect, i.e., release of trace contaminants, was investigated separately and the results are reported in Appendix F, Crystalline Matrix. Long-term dispersion of the sediments following disposal was investigated and is reported in Appendix E, Material Release. The biological implications of increased solids concentrations and reduced dissolved oxygen were investigated and reported in Appendix G, Physical Impact. The possibility of contamination of biological systems via the resuspension of polluted sediments was investigated and is reported in Appendix H, Pollutant Uptake and Appendix I, Pollutant Availability.

INDEX OF APPENDICES

The following is an index of appendices to be published in the Dredge Disposal Study:

CONVERSION FACTORS

If conversion from the Metric to the British system is necessary, the following factors apply:

LENGTH

1 kilometer (km)=10^3 meters=0.621 statute miles=0.540 nautical miles
1 meter (m)=10^2 centimeters=39.4 inches=3.28 feet=1.09 yards=0.547 fathoms
1 centimeter (cm)=10 millimeters (mm)=0.394 inches=10^4 microns (μ)
1 micron (μ)=10^{-3} millimeters=0.000394 inches

AREA

1 square centimeter (cm^2)=0.155 square inches
1 square meter (m^2)=10.7 square feet
1 square kilometer (km^2)=0.386 square statute miles=0.292 square nautical miles

VOLUME

1 cubic kilometer (km^3)=10^9 cubic meters=10^{15} cubic centimeters=0.24 cubic statute miles
1 cubic meter (m^3)=10^6 cubic centimeters=10^3 liters=35.3 cubic feet=264 U.S. gallons=1.308 cubic yards
1 liter=10^3 cubic centimeters=1.06 quarts=0.264 U.S. gallons
1 cubic centimeter (cm^3)=0.061 cubic inches
1 mg/l. = 1 part per million

MASS

1 metric ton=10^6 grams=2,205 pounds
1 kilogram (kg)=10^3 grams=2.205 pounds
1 gr (g)=0.035 ounce

SPEED

1 knot (nautical mile per hous)=1.15 statute miles per hour=0.51 meter per second
1 meter per second (m/sec)=2.24 statute miles per hour=1.94 knots
1 centimeter per second (cm/sec)=1.97 feet per second

TEMPERATURE

Conversion Formulas $\quad {}^{o}C = \frac{{}^{o}F-32}{1.8} \quad\quad oF = 1.8(oC) + 32$

ABSTRACT

Studies were conducted between 1972 and 1975 by the U.S. Army Engineer District, San Francisco, to assess the influence of local dredging and disposal operations on Bay water quality. Primary attention was given to the characterization of suspended solids loading and dissolved oxygen as modified by the operations. Emphasis was placed on these parameters because of the degree to which dredging and disposal affect concentrations and their importance in impact evaluation.

Both the dredging and the disposal operation were found to influence the dissolved oxygen concentration. The effects of the dredging operation were considerably less severe than those of the disposal operation. Reductions during dredging were detected only one quarter of the time. At the surface, overflow from a hopper dredge caused a depletion of approximately two parts per million. The oxygen concentration returned to ambient within about two minutes. At the sediment-water interface reductions of as much as four parts per million were recorded. Background concentrations returned after approximately eight minutes. Disposal from a hopper dredge resulted in surface reductions of approximately two parts per million lasing for two minutes. This reduction was similar to the surface reduction caused by dredging both in terms of intensity and duration. But near the bottom, sediment disposal can cause a significant oxygen depletion with each release. Reductions of up to six parts per million were observed. Ambient concentrations were regained after an average of three to four minutes, but could be influenced for as long as eleven minutes. During disposal operations in San Pablo Bay, oxygen increases did not exceed one part per million. The direction and intensity of these fluctuations is controlled by the chemical composition of the material, its contactable surface area and by aeration resulting from mechanical perturbations during the operation. The duration of a dissolved oxygen reduction is controlled by the contact time between sediment and water and by the intensity of its initial demand.

The suspended solids concentration during the dredging operation are generally an order of magnitude lower than concentrations during the disposal operation. During dredging the loading caused by the disturbance of the bottom and lifting-loading activities results in increases in the suspended solid concentration in increments of a gram (3 grams maximum). Disposal, on the other hand, increases the concentration in the bottom water in increments of tens of grams (22 grams maximum). Another difference is that increases in solids levels during dredging are confined basically to the channel and return to background levels within several hundred meters of the dredge, whereas increases at the disposal site can influence areas outside of the site boundaries.

Influences extend 1,000 meters beyond the impact zone. Both operations have very little effect on the upper water column (2 to 5 tenths of a gram).

During disposal the release of dredged sediments may result in a complete mounding of the sediments on the bottom or complete dispersion of the sediments over a large area. The controlling parameters are the type of sediment and the degree of disturbance to the sediment during the dredging operation. The cohesive properties of the sediment control the interaction of the sediment particles and the water column. A cohesive sediment with little disturbance (introduction and mixing with water) will descend through the water and mound on the bottom with little, if any, disturbance to the water column. If the cohesive properties are less because of added water or higher silt content, the slurry will entrain water during the descent, form a base surge cloud on the bottom and disperse over a large area. Initially currents and wind-wave conditions at the disposal site do not influence the movement of the density flow. Ultimately, as water entrainment reduces the unit mass current, wind-wave conditions will tend to control the long-term sediment transport and dispersion.

The evaluation of the physical conditions generated at the disposal site during a release requires information on the engineering properties of the sediment and type of dredging operation. The primary engineering properties are the grain size distribution and the liquid limit. With cohesive sediments, the release pattern (degree of initial dispersion or mounding) can be correlated with the liquid limit and the moisture content of the sediment generated by the dredging operation. The degree of initial dispersion or mounding depends on whether the sediments act as a solid, a liquid or a transitional slurry. Cohesive sediments require a disturbance in terms of water added; whereas, sands, regardless of water content, act as a solid phase. The actual intensity, duration and area influenced by sediment loading, hence, is different for dredging and disposal operations. However, the nature of the interactions within either operation is primarily controlled by the same three factors: (1) sediment properties, (2) equipment and operation, and (3) site conditions.

DREDGE DISPOSAL STUDY
SAN FRANCISCO BAY AND ESTUARY

APPENDIX C

WATER COLUMN

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APPENDIX C, WATER COLUMN

INTRODUCTION

"Water quality" has become one of the bywords of an environmentally conscious American public. Recent government publications (Council on Environmental Quality, 1970; Environmental Studies Board, 1972) and Congressional Legislation (Public Laws: 92-500, Federal Water Pollution Control Act Amendments of 1972; 92-532, Marine Protection, Research and Sanctuaries Act of 1972; and 93-523, Safe Drinking Water Act of 1974) exemplify the increased emphasis the government is placing on control of water pollution. One of the ways the United States Army Corps of Engineers is participating is by focusing on the degree and duration of water quality degradation associated with their dredging and disposal activities (Boyd et al, 1972). The San Francisco District has a study of the environmental effects of dredging and disposal operations in San Francisco Bay. A separate element of that study was designed to quantify the changes in water quality in project and disposal areas during dredging operations. This information has been integrated with the results of four other study elements (Appendices F, Crystalline Matrix, G, Physical Impact, H, Pollutant Uptake and I, Pollutant Availability). It provides an evaluation of the probability of adverse chemical or biological effects being produced directly by the changes in water quality. This report describes the methods and procedures used to characterize water quality and the results of routine monitoring and special studies. Although the results have some general application, it should be remembered that the study is site specific to San Francisco Bay.

Investigations in the late sixties (U.S. Army Corps of Engineers, 1967; Brown and Clark, 1968) indicated that dredging and disposal operations could cause degradation of water quality downstream of the activity. The principle influences were the direct result of the resuspension of bottom sediments. Resuspension of anaerobic sediments has been shown to cause oxygen consumption rates significantly above quiescent benthal rates (Isaac, 1965; Servizi et al, 1969). Thus during a dredging or disposal operation the areal dissolved oxygen concentration can be reduced from near saturation levels (background) to fifty percent saturation or less (Slotta et al, 1973; Maurer et al, 1974). The actual degree of reduction is dependent on the chemical nature of the inplace sediment. Elevated suspended solids concentrations have been found to be responsible for mechanical damage to respiratory surfaces, disruption of pumping and feeding mechanisms and reduction in primary productivity (Sherk, 1971; Stone et al, 1974). The mechanical resuspension of sediments can cause increases of the suspended solids concentrations of more than five times background levels during dredging operations (Wakeman et al, 1975); and as much as ten times background levels during disposal operations (May, 1973).

U.S. Fish and Wildlife Service (1970) prepared a special report for the Corps of Engineers documenting their studies in selected reaches of San Francisco and San Pablo Bays. The studies included laboratory and field studies of the effects of dredging and disposal operations on water quality, benthic organisms, free swimming invertebrates, and demersal fish. Water samples taken near the bottom following dumping at the San Pablo Bay disposal site showed a near bottom turbidity level of 2000 Jackson Turbidity Units (JTU) and dissolved oxygen content of 0.1 ppm. The highest surface turbidity was 875 JTU and dissolved oxygen content 5.7 ppm. Turbidity and dissolved oxygen returned rapidly to pre-disposal levels following the operation. These changes in water quality were severe enough to indicate that operations in San Francisco Bay could be causing adverse environmental responses.

The objective of this study has been to ascertain the effects of dredging and disposal operations on the water quality of San Francisco Bay with particular emphasis on the degree and duration of associated sediment resuspension. To achieve this objective water quality monitoring was performed in several areas of the Bay influenced by dredging and disposal operations during 1972-1975. The purpose was to record and quantify deviations from background of suspended solids loading, light transmission, dissolved oxygen content, temperature, salinity/conductivity and pH of the water column.

SAN FRANCISCO BAY WATER CONDITIONS

The San Francisco Bay system is composed of essentially two physical regimes: sediment and water. The two regimes are interrelated and closely associated in their chemical and physical properties. Sediment quality is the subject of Appendix B, Pollutant Distribution Study. It describes the Bay's physical estuarine processes (tides, currents, depositions, etc.) and pollutant sources. That information will not be reiterated in detail in this appendix and should be reviewed to enable development of a holistic impression of the physical system.

The Bay is the most important natural resource found in the San Francisco metropolitan area. Without this prime ingredient the region would lack its moderate climate, innate serenity and probably much of its large human population. Therefore, to maintain an acceptable quality of life for the inhabitants of the region, care must be taken to guard this resource.

The quality of the estuarine waters in the region has deteriorated since the period when the shores were bordered by salt marshes. The degree of degradation associated with the increase in industrial man's activities is difficult to assess. It may not be critical to maintenance of acceptable water quality conditions. With approximately five million people presently surrounding the estuary, the probability of the waters returning to near pristine conditions is slight. However, with intelligent use both man and the aquatic environment can survive and prosper.

This section describes the geomorphology of the estuary, and its present water quality condition. It discusses some of the extraneous influences which could modify this condition on either a short or long term basis. The characterization of present water quality conditions provides a baseline from which evaluation of human activities can be assessed. This document is concerned primarily with the effect of dredging and disposal operations on water quality. The impacts associated with these operations will be discussed in subsequent sections.

General Description of Bay

What is an estuary? Many definitions have been offered historically. One of the simplest was suggested by the American Geological Institute (1962), "Drainage channel adjacent to the sea in which the tide ebbs and flows." Tully and Barber's (Sears, 1961) definition incorporated fresh water as an important factor, "The basic requirement for . . . an estuarine system . . . is the presence of a supply of fresh water which exceeds the losses by evaporation or freezing." One of the most rigorous definitions was proposed by Pritchard (Lauff, 1967), "An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage."

San Francisco Bay by any of these definitions is an estuary. Geomorphologically it is a semi-enclosed drowned valley through which passes the drainage of the Central Basin of California and is subject to tidal action from the adjacent Pacific Ocean debouching through the Golden Gate. The estuary has a bifurcation landward of the Golden Gate with a southerly arm stretching about 35 miles to the southeast and a northerly arm that extends about 22 miles north then abruptly turns in an easterly direction for about 20 miles to the Sacramento-San Joaquin Delta. The southern arm is South San Francisco Bay and the northern arm passes through Central San Francisco Bay and includes San Pablo Bay, Carquinez Straits and Suisun Bay (see Figure 1). This system of bays has widths of up to 12 miles, and encloses an area of 396 square miles at mean lower low water, and 460 square miles at mean higher high water. San Francisco Bay proper ranges in depth from the shoal areas near shore (less than 15 feet) to the 382-foot depth at the Golden Gate. San Pablo Bay, which is considerably shallower than San Francisco Bay proper, ranges in depth from extensive shoal areas (northern shallows approximately 5 feet) to 94 feet in San Pablo Strait. Of the total Bay system about 50 percent is less than 10 feet deep and about 68 percent is less than 20 feet deep measured from mean sea level.

The University of California conducted a comprehensive study of San Francisco Bay from July 1960 to July 1964 in which the Bay's hydrologic system was characterized (Selleck et al, 1965). They found that the mean annual rates of total advective flow during the survey period were -77 and +20,070 cubic feet per second (cfs) in the southern and northern reaches, respectively. The maximum observed positive and negative monthly flow rates were 2,230 and -1,320 cfs in the southern reach and 101,400 and -480 cfs in the northern reach. The southern reach was generally a neutral arm because of the relatively insignificant advective flow in the region. The northern arm, however, was a significantly positive system during most of the survey period as a result of the Delta outflow. From Corps studies (USACE, 1967) the mean annual tidal prism of the southern reach was about 3×10^{10} cubic feet. This value was about thirty percent greater than the number of cubic feet determined for the northern reach. Using tidal wave amplitudes, amplitude time lags, and phase shifts it was concluded that the tidal wave was predominantly a standing wave in the southern arm and a progressive wave undergoing extensive frictional decay in the northern arm. The magnitude of the advective flows significantly influences the characteristics of this northern tidal wave.

The tides provide a major portion of the turbulent energy causing estuarine mixing (Klingeman and Kaufman, 1965). Secondary sources of turbulence include river inflow, currents generated by lateral constrictions or bottom configuration and wind-wave phenomena. The degree of turbulence in an estuary dictates the distribution of water properties. Estuarine mixing structure has been classified in terms of salinity as (a) vertically mixed or well-mixed, (b) slightly stratified

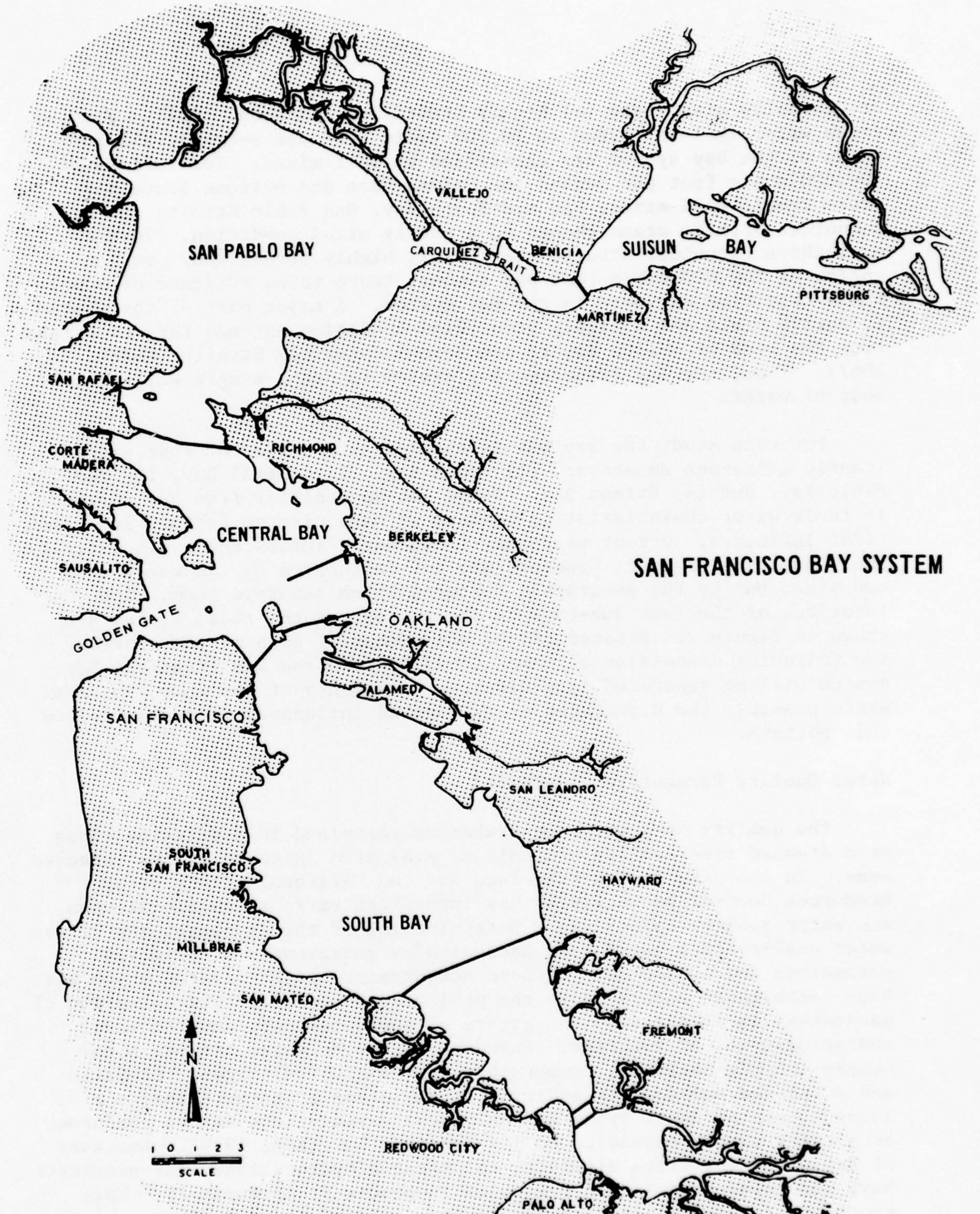

SAN FRANCISCO BAY SYSTEM
SAN PABLO BAY
VALLEJO
CARQUINEZ STRAIT
BENICIA
SUISUN BAY
MARTINEZ
PITTSBURG
SAN RAFAEL
RICHMOND
CORTE MADERA
CENTRAL BAY
BERKELEY
SAUSALITO
GOLDEN GATE
OAKLAND
ALAMEDA
SAN FRANCISCO
SAN LEANDRO
SOUTH SAN FRANCISCO
HAYWARD
SOUTH BAY
MILLBRAE
SAN MATEO
FREMONT
N
1 0 1 2 3
SCALE
REDWOOD CITY
PALO ALTO
ALVISO

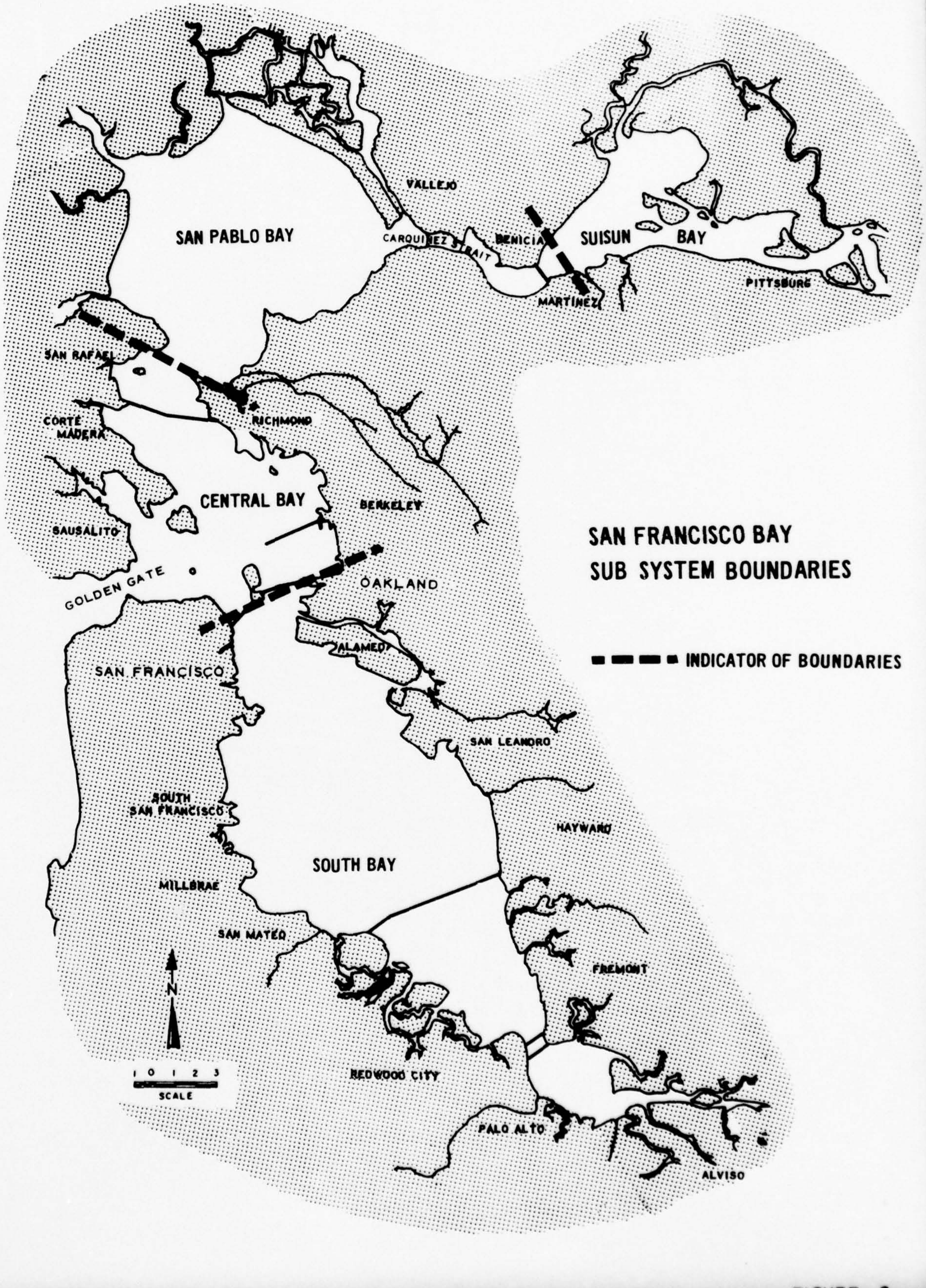
FIGURE 1

or partially mixed, and (c) highly stratified (Pickard, 1963). For low fresh water inflows (5,000 to 10,000 cubic feet per second), all portions of the Bay system are classified as well mixed. For inflows of 100,000 cubic feet per second the Golden Gatė and extreme South Bay areas remain well-mixed, but mid-South Bay, San Pablo Straits and Carquinez Straits areas change to a partly mixed condition. In the area above Carquinez Straits the flow is highly stratified. For an inflow of 200,000 cubic feet per second, there is no evidence of a well-mixed condition anywhere in the Bay system. A major part of the system is partly mixed and a highly stratified condition extends far downstream from the head of Suisun Bay to and beyond Carquinez Straits (USACE, 1967). Thus, the San Francisco Bay system is not a single well-defined body of water.

For this study the Bay was delineated as a series of four significantly different sub-bays: (1) South Bay, (2) Central Bay, (3) San Pablo Bay, and (4) Suisun Bay. These sub-bays differ from one another in their water characteristics because of many diverse factors including tidal influence, current patterns, fresh water inflow and human activity. The boundaries of each, however, are not delineated by the water mass contained but by the geographic features which separate them. The locations of the four sub-bays in the context of the total system are shown on Figure 2. Because of the uniqueness of each of these areas, the following discussion of water conditions in the San Francisco Bay system will be separated into discrete treatments of the four sub-bays. Where possible the discussion of extraneous influences will also follow this pattern.

Water Quality Parameters Considered

The quality of a water mass whether contained in a drinking glass or a drowned river valley can only be evaluated in terms of its intended uses. In the case of San Francisco Bay the California State Water Resources Control Board (1974) has identified various beneficial uses and water quality objectives. Determination of the acceptability of the water quality of a water body necessitates measurement of selected parameters and comparison of those measurements with criteria which has been established according to the projected water use. The selection of parameters is dictated by the nature of the water body and the water characteristics of interest. Standard estuarine water quality parameters include salinity, temperature, pH, dissolved oxygen, turbidity and suspended solids. In addition to these basic characteristics a large number of other types of analytical examinations may be performed on a water sample depending on its intended use (EPA, 1974). Analyses of Bay water for trace elements, chlorinated hydrocarbons, and nutrients have been conducted in other studies (Appendix H; Appendix I). This report will cover monitoring of the six standard characteristics as they related to the dredging operation. A brief description of each of these characteristics and the methods for their determination follows.



SAN FRANCISCO BAY
SUB SYSTEM BOUNDARIES

▬ ▬ ▬ INDICATOR OF BOUNDARIES

FIGURE 2

Salinity. The salinity of water is important in maintaining the proper osmotic relationship between the protoplasm of an organism and the water. Variations in salinity operate mainly as a selective agent determining the composition of species that inhabit a region rather than determining the fertility of the region.

The formal definition of salinity and the technique established for its determination were developed by an International Commission in 1901 (Forch, Knudsen, and Sorensen, 1902). Their definition is "the total amount of solid material in grams contained in one kilogram of sea water when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all organic matter completely oxidized". The technique established by the International Commission is rarely used because it is too difficult and time consuming. Instead, other techniques are employed to measure the salt content of water, the most common are the determination of chlorinity and electrical conductivity. Chlorinity is determined chemically by argentometric titration of the halogens in sea water. The conductivity method has the advantage that few manipulations are needed to obtain a value and no great skill is necessary. Two types of conductivity measurements have been used, electrodes and induction. The electrode method has calibration drift problems because of possible polarization and fouling of the electrodes. Such problems are eliminated by the induction method in which the sea water solution is made a conducting loop in a transformer. This was the method utilized during the course of the study. With the development of inductive conductivity methods, salinity was redefined in terms of conductivity ratios:

Salinity (parts per thousand) = 1.806 Conductivity

Temperature. Temperature is a factor of prime importance in the aquatic environment because of its affect on the physiological processes of animals and plants, especially rate of metabolism, growth and reproduction. For example, temperature strongly influences the rate at which calcium carbonate can be precipitated by molluscs and sponges in the formation of skeletal parts, shells and spicules. Equally important is close association with and influence of temperature on water characteristics such as the partial pressure of oxygen and other gases, viscosity and density distributions. Normally, temperature measurements are made with a mercury-filled thermometer. Depth temperatures used in oceanographic studies may be taken with a reversing thermometer, a thermophone or a thermistor. The thermistor, which was used in this study, is the most convenient and also capable of the greatest accuracy.

pH Value. The pH is a measure of the hydrogen ion concentration or more correctly the hydrogen ion activity. Pure distilled water dissociates into hydrogen and hydroxyl ions:

$$H_2O = H^+ + OH^-$$

For expressing the hydrogen ion concentration a logarithmic scale is used where pH is the logarithm of the reciprocal of the ion concentration in moles per liter. The practical pH scale extends from 0 (very

acidic) to 14 (very alkaline). The middle of the scale (pH 7) corresponds to neutrality at 25 degrees centigrade. The pH of most natural waters is between 4 and 9 with the majority of waters being slightly alkaline (greater than 7) because of the presence of carbonate and bicarbonate. The pH affects the rate of chemical reactions and the activity coefficients and thus the importance of maintaining the proper pH is vitally important to life. The pH of a solution may be determined in various ways but all are essentially either colorimetric or electrometric. The colorimetric method utilizes certain organic compounds as indicators which have the property of changing color over a given range of hydrogen ion concentrations. This method requires less expensive equipment but suffers from severe interference contributed by color, turbidity, temperatures, high salinity and various oxidants and reductants. For these reasons the electrometric method is more commonly used in water quality studies. There are several types of electrodes which have been used in pH determinations. This study employed the most commonly used electrode, the glass electrode in combination with a reference potential electrode and commercial pH meter.

Dissolved Oxygen. Oxygen is indispensable to the life processes of all organisms. Normally, it is only available for metabolic activities when it is in solution in a free state. Very few organisms, mainly anaerobic bacteria, are able to utilize oxygen complexed with organic molecules. Thus, to continue respiration most organisms must have a source of free oxygen. In water the reservoir contains only about 9 mg/l whereas the atmospheric reservoir contains over 200 mg/l. Obviously, reduction in the oxygen level of the environment by introduction of oxygen consuming materials is a much more critical problem to aquatic organisms than air-breathing life. Therefore, maintenance of sufficient oxygen concentrations for aquatic respiration is essential and measurement of dissolved oxygen is a primary parameter in water quality monitoring.

The dissolved oxygen concentration is typically determined either by the Winkler (iodometric) method and its modifications or by the electrometric method using membrane electrodes. The Winkler method is a titrimetric procedure and is based on the oxidation of manganous hydroxide. In the electrometric method an oxygen-sensitive membrane electrode is used. It is composed of two solid metal electrodes in contact with a certain volume of supporting electrolyte separated from the test solution by a membrane. The selection of either of these two methods is determined by the degree of interferences present and the accuracy desired.

Turbidity, Transparency and Suspended Solids. Turbidity and transparency are poorly quantifiable parameters. They give a relative indication of the amount of suspended matter in water. Transparency is typically a measure of surface turbidity and can be contingent on the amount of algal growth. These parameters are defined by the degree of attenuation or reduction in light intensity passing through water. The light decrease is the result of not only blockage by particulates (including minerals,

finely divided organic and inorganic matter, and plankton) but by dissolved solids and color. In general, any correlation between turbidity-transparency and the weight concentration of suspended matter is fortuitous. The shape, size and refractive index of particulate minerals are of great importance optically but are only indirectly related to the concentration and specific gravity of the suspended solids. Determination of actual suspended solids concentrations requires filtering, drying and weighting of samples. Measurement of light scattering by eye or optical instruments is a less expensive and more convenient method to provide a relative basis for comparing the cloudiness of water. The simplest technique for the determination of surface turbidity or transparency is to lower a secchi disc into the water until it disappears. Readings are given in feet of transparency. The standard optical instrument used is the Jackson Candle turbidimeter. There are other transmissometers and nephelometers which have come into common usage. However, owing to the fundamental differences in the optical systems, the results obtained from these different systems will frequently not correlate even though the instruments are all precalibrated against the candle turbidimeter. Additionally, the different instruments report their measurements in one of several unit systems. Jackson turbidity units (JTU), Formazine turbidity units (FTU), nephelometric units (NU) and % transmission are the principal unit categories. Results reported in one system are not necessarily comparable to results reported in another system. Comparison of readings and the estimate of suspended matter concentration derived from optical readings are of little value when quantitative investigations are required. When such investigations are necessary, suspended solids should be measured simultaneous with turbidity for evaluating the particulate load of the water mass. This information is essential for assessing biological effects resulting from sediment loading of the water column. Each of these basic parameters is essential to the elementary characterization of a water body. Designating any one parameter as being more important than another is not possible in the aquatic environment where numerous factors operate simultaneously.

Seasonal and Areal Variations

To provide a quantitative evaluation of the changes which occurred in water quality during dredged and disposal operations, measurements of background levels of each parameter (dissolved oxygen, salinity, conductivity, temperature, turbidity, suspended solids, and pH) were monitored in 1973-75. Measurements were made prior to and following operations in various project areas. The post-operation surveys were scheduled after a sufficient period of time to allow the water column to return to natural conditions, i.e., without the influence of dredging operations. The background measurements were restricted to the time frame in which particular dredging and disposal operation occurred. This was to enable comparisons of parameter levels influenced and not influenced by dredging with minimum seasonal fluctuations. The dredges used for the majority of maintenance work by the San Francisco District

are only available during the late fall to early springs months. This resulted in data generally limited to the central and northern parts of the Bay during the fall and winter seasons. By using previously published data of water quality characteristics and measurements obtained during this investigation a general description of seasonal hydrological conditions was developed.

During the period 1960 to 1964, the Sanitary Engineering Research Laboratory (SERL) of the University of California, Berkeley, sponsored by the California State Water Quality Control Board, investigated water and sediment quality and geophysical characteristics of San Francisco Bay (Storrs et al, 1966). In 1974, Stanford Research Institute (Biological Community, Appendix D) measured water and sediment parameters and sampled benthic biota at selected project areas and disposal sites. The data from the above study was supplemented with data obtained from the Environmental Protection Agency's (EPA) STORET system for the period 1970 to 1975 to characterize the present water quality in each of the four sub-bays. The maximum, minimum and mean value for each of the basic water quality parameters are presented for each sub-bay in Table 1 (SERL) and Table 2 (SRI and EPA). The parameters are graphically displayed in Inclosure 1.

TABLE 1

SANITARY ENGINEERING RESEARCH LABORATORY
WATER QUALITY DATA
1960-1964

PARAMETER		SOUTH BAY	CENTRAL BAY	SAN PABLO	SUISUN BAY
CHLOROSITY	max	18.5	18.0	16.0	8.5
(Cl^-, mg/l)	min	10.5	15.5	3.5	0.02
	mean	15.0	16.5	10.5	2.5
EST. SALINITY	max	32.2	31.4	28.0	14.8
(ppt)	min	18.1	27.1	5.8	0.04
	mean	26.2	28.9	18.1	4.2
TEMPERATURE	max	22.5	18.3	19.3	21.3
(^oC)	min	10.0	10.7	8.3	6.9
	mean	15.5	13.8	14.9	15.0
DIS. OXYGEN	max	8.4	8.3	9.3	10.2
(mg/l)	min	3.3	6.3	6.8	6.6
	mean	6.3	7.3	8.0	8.4
pH	max	8.1	8.1	7.9	8.0
(Std. Units)	min	7.5	7.5	7.2	7.4
	mean	7.8	7.9	7.7	7.7
SUS. SLDS	max	110	48	245	112
(mg/l)	min	12	6	13	34
	mean	42	18	45	65
TRANSPARENCY	max	6.2	9.0	3.5	1.5
(feet)	min	0.5	1.0	0.5	0.5
	mean	2.7	4.6	1.6	0.9

TABLE 2

STANFORD RESEARCH INSTITUTE &
ENVIRONMENTAL PROTECTION AGENCY STORET
WATER QUALITY DATA

1970-1975

PARAMETER		SOUTH BAY	CENTRAL BAY	SAN PABLO	SUISUN BAY
SALINITY	max	30.0	30.5	23.5	-
(ppt)	min	18.0	18.0	1.5	-
	mean	23.7	24.5	11.5	-
TEMPERATURE	max	19.5	19.8	20.0	26.0*
(^{o}C)	min	10.9	10.0	9.8	6.0*
	mean	14.5	14.4	14.4	16.6*
DIS. OXYGEN	max	9.3	9.0	10.2	11.8*
(mg/1)	min	6.5	6.6	6.7	6.8*
	mean	7.9	7.9	8.6	9.4*
pH	max	8.2	8.0	8.0	8.6*
(Std. Units)	min	6.9	7.3	7.3	6.8*
	mean	7.7	7.7	7.7	7.7*
SUS. SLDS.	max	-	47*	123*	245*
(mg/1)	min	-	26*	33*	11*
	mean	-	36*	77*	82*
TRANSPARENCY	max	3.8*	5.3*	-	0.8*
(feet)	min	0.8*	3.0*	-	0.76*
	mean	2.4*	4.2*	-	0.78*
TURBIDITY	max	45	24.0	390	140*
(NU & FTU*)	min	1	5.0	10	17*
	mean	20	14	129	52*

NOTE: DATA "STARRED" FROM EPA STORET SYSTEM; ALL OTHERS FROM STANFORD RESEARCH INSTITUTE SURVEY (Biological Community, Appendix D).

The two data sets (Table 1 and 2) allow comparison of historic water quality data, compiled ten to fifteen years ago, with more contemporary data.

Salinity. SERL presented their salinity determination in terms of chlorosity. To enable comparisons with the more recent data, the chlorosity values were converted to an estimated salinity value by dividing by the density of brackish water (15 o/oo) at 20 degrees C., multiplying by 1.805 and subtracting 0.03. Contrasting the 1960-1964 data to the 1974 data shows that the values for South Bay correspond between decades but the Central and San Pablo Bay readings were more saline in the early sixties. The higher readings are probably due to lower Delta outflows which occurred during this period (CSRA) and DWR, 1974). Central Bay is obviously affected by the Pacific Ocean and the salinity data reflects this influence. South Bay closely parallels the Central Bay salinity regime suggesting that flushing of South Bay is dependent on Central Bay water movements. When flushing is minimal, i.e., late summer, South Bay salinity may increase above the levels found in Central Bay. This increase is the result of evaporation from the sub-bay causing a net loss of water, concentrating dissolved solids. San Pablo Bay and Suisun Bay are progressively fresher from their lower to upper ends. Freshness is also cyclic depending on the periodicity of Delta and other tributary outflows. Salinity in all sub-bays is generally lowest during the rainy season in January, February and March and highest in late summer, September and October.

Temperature. The temperature is relatively constant between decades and sub-bays. Minor variances are detectable. The mean temperature of Central Bay is the coldest of the sub-bays. Again, this is indicative of oceanic mediation. However, lowest temperatures were recorded in Suisun Bay. This is a consequence of the seasonal, snow-melt runoff which drives water temperatures down during the late winter period. This phenomena also affects San Pablo Bay but to a lesser extent. Maximum water temperatures were observed in Central Bay during August and in South, San Pablo and Suisun Bays, during July.

Dissolved Oxygen. The mean dissolved oxygen concentration increased in all sub-bays between the early sixties and the mid-seventies. The improvement is consistently greater than one-half part per million and in South Bay was approximately one and one-half part per million. This improvement can be attributed to the increased treatment of municipal and industrial wastewaters prior to discharge to the Bay. The minimum reading in 1974 was 6.5 mg/l, which is well above the concentration considered necessary for respiration by estuarine biota. Highest readings were recorded in Suisun Bay during both decades, which is characteristic of fresh, cold, turbulent water. Lower salinity and temperature of a water mass permits higher concentrations of dissolved oxygen. If this water mass is turbulent additional oxygen may be introduced beyond the 100 percent saturation level. On the other hand, quiescent, warm water as found in South Bay during late summer holds very little oxygen. The problem becomes acute for aquatic life when there is an additional demand placed on the oxygen concentration by waste loading and algae.

pH. The hydrogen ion concentration or pH was less variable between sub-bays during 1960-1964 (ranging from 7.2 to 8.1) than during 1970-1975 (ranging from 6.8 to 8.6). Although none of the values are outside of typical seawater pH activities, the greater discord in the seventies data was possibly produced by high freshwater inflows disrupting the carbonate and silicate buffering systems. In general, there did not seem to be a pattern between decades, sub-bays or seasons.

Turbidity and Suspended Solids. Turbidity can not be compared between decades except for surface effects (transparency). Transparency was generally similar, however, maximum readings were higher in the sixties. Comparing the suspended solids between decades indicates that the Bay system was generally carrying a larger suspended solids load in the early seventies. Again as with the salinity anomaly between decades this is probably related to freshwater inflows. In both decades, however, the Central Bay was always the clearest. San Pablo and Suisun Bay are both seasonally influenced by the suspended sediment introduced and carried by the freshwater outflow from the Delta. Both San Pablo and Central Bay had maximum turbidities during late May and June during the aforementioned snow-melt runoff season. South Bay's maximum was in March and was probably associated with the greater volume of water moving down into the Bay from the Delta during the rainy season. All three sub-bays had minimums in summer (September). Shortly after this turbidity increased probably because of wind-wave resuspension.

Vertical Variations

Besides seasonal and areal variations in San Francisco Bay water conditions, there are also vertical variations. Using background monitoring data collected from dredging and disposal projects, vertical trends were developed for the Fall-Winter periods. These trends are presented in Inclosure 2. Arrows are used to indicate the direction in which a parameter tends to increase in magnitude through a vertical profile from 1 to 10 meters. Several general conclusions can be drawn from these plots.

Conductivity. In all cases conductivity increased with depth. This is a function of water density as influenced by differing dissolved salt concentrations. As the concentration of dissolved salts increases in a water mass, the density of that mass increases. This results in less dense or fresher water overlying denser or more saline water.

Salinity. Salinity variations behave in the same manner as conductivity because both are measurements of the dissolved salts in solution. Salinity also typically increases with depth.

Temperature. The vertical temperature distribution is also related to the density of water. Two-thirds of the profiles have temperature gradients which proceed from the less dense, warmer water on the surface to colder water below. The other third shows a temperature inversion.

Typically, these inversions occurred during the later winter (January and February) and are the result of cold fresh water from storm runoff overflowing the more saline estuarine water. Temperature influences density less than the dissolved salt content. The inversion in Mare Island Strait during 25 October 1973 was probably related to tidal influence.

Dissolved Oxygen. The concentration of dissolved oxygen in a water mass is influenced by both the temperature and the salinity of that mass. As salinity and temperature increase, the ability of water to hold dissolved oxygen decreases. Additionally, phytoplankton populations will increase the dissolved oxygen concentration during periods of photosynthesis and will decrease the concentration during periods of respiration. Turbulence caused by wind-wave activity can also increase surface oxygen concentrations by introducing oxygen into the water mass from the atmosphere. Many factors influence the dissolved oxygen concentration of the water column. Typically, the oxygen concentration would be expected to decrease with depth because of surface aeration and benthal oxygen demand. However, periods with no vertical trend or with a reverse trend have been observed. Exact explanations of such trends are unavailable.

pH. Because of the buffering capacity of both San Francisco Bay water and sediment, the pH range in the system is very limited. The pH is commonly uniform throughout the water column and is shown as no trend. In some cases the pH was less in the upper water column than the lower water column. This is possibly a function of phytoplankton driving the surface water to a lower pH by utilization of carbon dioxide. This shifts the carbonate system such that there is an increase in the hydrogen ion concentration in the upper water column. Observed inverses, i.e., high pH in the upper water column, might be explained by runoff influences or municipal-industrial discharges. Sufficient information is not available to verify the explanation.

Turbidity. Turbidity was determined using a 10 centimeter transmissometer. In San Francisco Bay turbidity is commonly uniform throughout the water column. In some cases, it is higher in the upper water column than the lower water column due to sediment laden fresh water from the Delta overflowing the more saline estuarine waters.

Flushing Patterns

Water circulation or flushing characteristics of the Bay determine the potential to disperse discharged materials.

Using the Bay Model, the characteristics of the flushing system were studied and analyzed through the use of dye tracers (USACE, 1963). Although the dye does not necessarily represent sediment movements, it does represent mass movement and mixing. These tests were conducted for

the U.S. Public Health Service to determine through simulated contaminant releases, the flushing characteristics of industrial and municipal wastes normally being discharged at major outfalls in shallower waters. The USPHS was concerned with the bio-chemical oxygen demand (BOD) of waste discharges into the Bay. Lower dissolved oxygen levels result from the assimilation of such wastes on the oxygen content of the receiving waters. This effect develops over a definite period of time at a rate decreasing from the time the waste enters the water until such a reaction is completed. The following is a brief summary of the results of this test for each sub-bay.

The dye released in South Bay essentially remained in that area for the duration of the test (40 tidal cycles). Maximum dye concentrations in relation to the amount of dye released were higher than in other sections of the Bay. The capacity of the South Bay to assimilate wastes is limited by the poor mixing and flushing characteristics obtained in that area.

The Central Bay is one of the most important sections of the Bay. The large quantities of water flowing through the Golden Gate cause mixing and flushing action ideally suited for waste disposal. Dye releases in this area resulted in low concentrations with respect to amount of dye released.

San Pablo Bay, like Central Bay, is rather turbulent especially in deep water. Dispersion characteristics are such that a high degree of mixing can be expected. Dye released in San Pablo Bay and Carquinez Strait was traced in almost all sections of the model before a period of 20 tidal cycles had passed.

The inflow from the Sacramento and San Joaquin Rivers has considerable effect on the dispersion characteristics of the Suisun Bay area. The fresh-water inflow adds a net downstream velocity which not only increases the magnitude of the dispersion but also causes significant flushing. Although relatively high concentrations of dye persisted in Suisun Bay for the first 10 tidal cycles of the test, the reduction of dye from cycle to cycle was considerable. Dye released was evident in many parts of the model by the fifth cycle of a 40 tidal cycle test.

SAN FRANCISCO BAY DREDGING OPERATIONS

The dredging process is comprised of three separate and distinct actions - excavation, transport and redeposition. In the Bay dredging is necessary to provide navigation improvements and maintenance. Improvements involve the construction of new harbors and their facilities or deepening of channels. Maintenance of existing projects is necessary to remove shoal materials which move into the channels during sediment inflow or recirculate conditions.

Types of Equipment

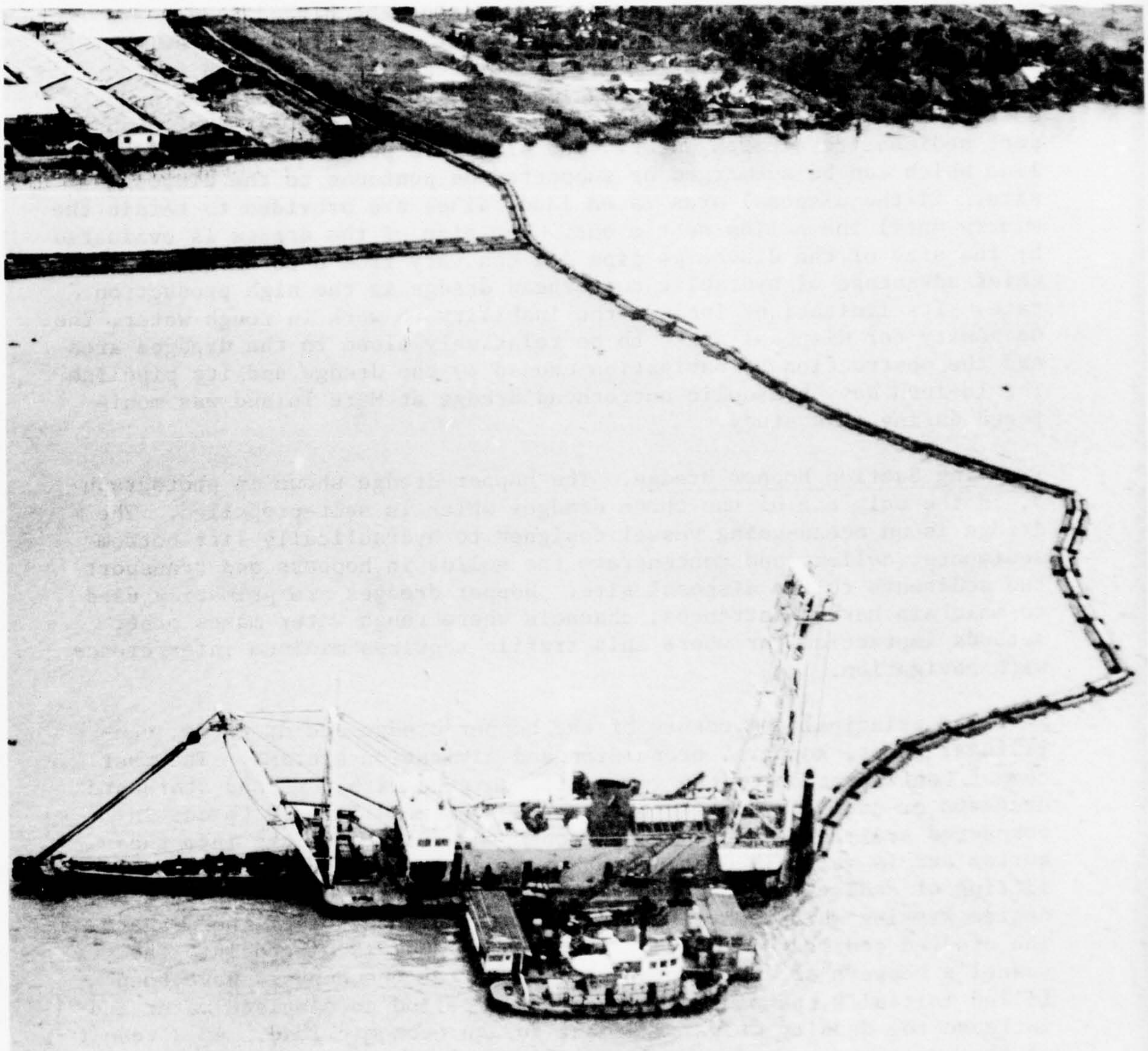
In San Francisco Bay excavation is normally accomplished with either the clamshell dredge, hydraulic cutterhead dredge or trailing suction hopper dredge. Maintenance of levees is accomplished with draglines. The following paragraphs briefly describe the operations of each of the first three pieces of equipment.

Clamshell Dredge. The bucket clamshell dredge shown in photograph 1, is commonly used in San Francisco Bay because of the confined conditions in which the equipment operates, i.e., around piers and docks, and the soft cohesive nature of the materials typically excavated. The principle components include a hoisting machinery, swinging boom, anchoring system and bucket. The operator controls the "cut" by lowering and raising the bucket and swinging the boom. The dredge is advanced by means of anchor lines and spuds. The clamshell dredge has only cut and lifting capabilities. Unless the material is disposed adjacent to the channel, separate transport and disposal equipment is required. Typically this includes at least two bottom-dump scows and a supporting tug for positioning the scows and transporting to the designated disposal site. Slow excavation is the chief limitation of this dredge while the ability to operate in confined areas to almost any depth and to work continuous even with long haul distances are its chief advantage. The size of the dredging operation is evaluated by size of the clamshell in cubic yards. The dredge Boston with an 18 cubic yard clamshell was monitored during these studies.

Hydraulic Cutterhead Dredge. The hydraulic cutterhead dredge shown in photograph 2, continually removes sediments with simultaneous transport via a pipeline. The hydraulic dredge can be the plain suction type, which is limited to working in free-flowing sediments, or equipped with a cutterhead to break up the sediments at the intake of the suction pipe. If equipped with the proper head the dredge can dig in substrates ranging from light silts to heavy rock. The components of the dredge include a cutter, ladder with suction pipe, centrifugal pump, anchoring system, and pipeline. The centrifugal pump creates a pressure differential resulting in lifting of bottom sediments and pumping through the

Clamshell Dredge

PHOTOGRAPH 1

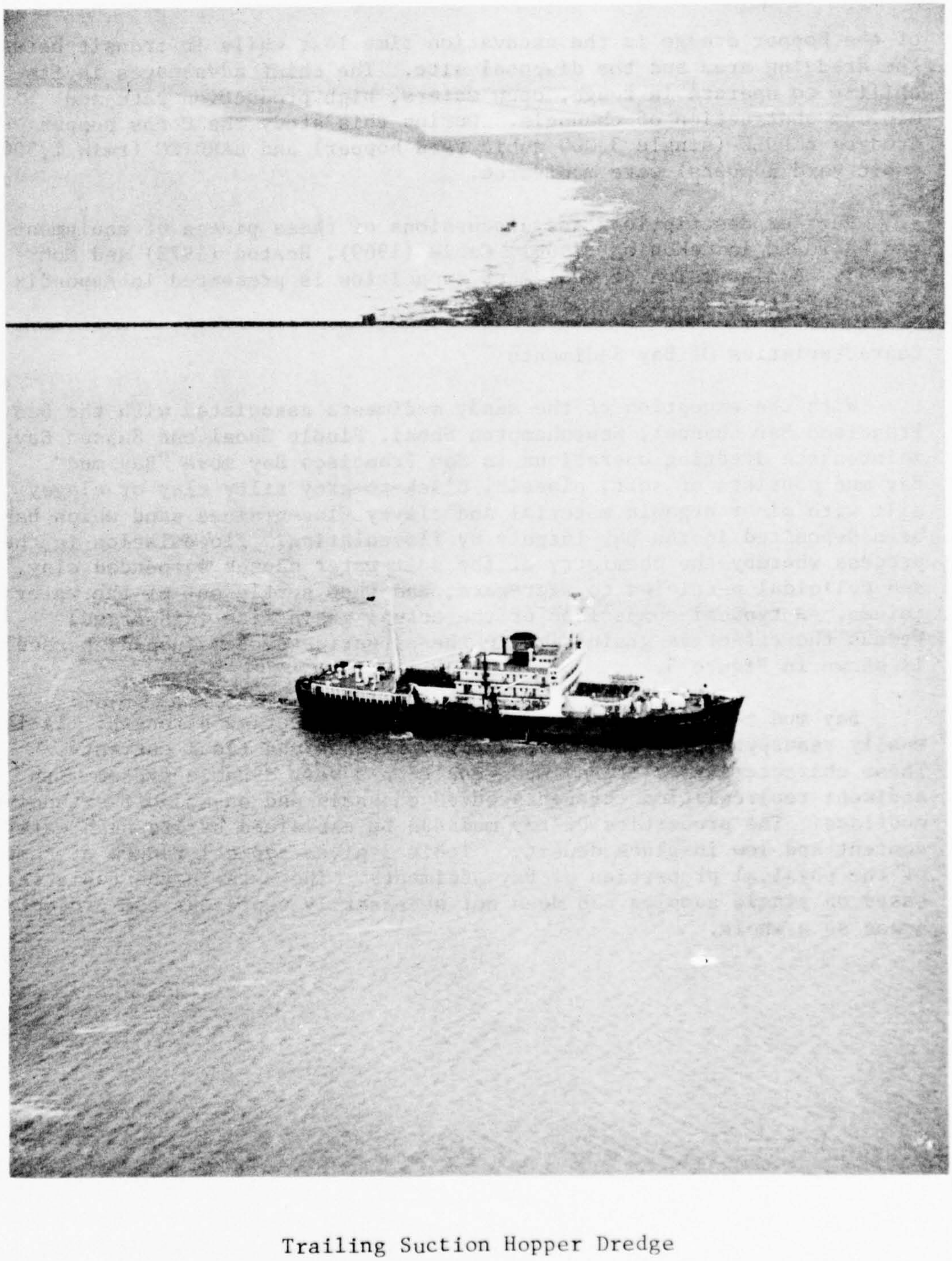


Hydraulic Cutterhead Dredge

pipeline to the disposal site. The pump is usually a large capacity, single stage type that has sufficient clearance to pass anything that can move through the cutterhead and enter the suction pipe. The depth of "cut" is controlled by lowering and raising the hinged ladder and suction pipe. Horizontal control of the cut is achieved with swing lines, moving the dredge in an arc. The dredge is positioned and advanced by means of anchors, swing lines and spuds. The cutting and suction introduces additional water to the system in a ratio of about 1 part sediment to 4 parts water. The slurry is pumped through the pipeline which can be submerged or supported on pontoons to the disposal site. If the disposal area is on land, dikes are provided to retain the slurry until the solids settle out. The size of the dredge is evaluated by the size of the discharge pipe and can vary from 6 to 42 inches. The chief advantage of hydraulic cutterhead dredge is the high production rate. Its limitations include the inability to work in rough water, the necessity for disposal sites to be relatively close to the dredged area and the obstruction to navigation caused by the dredge and its pipeline. The 18-inch Navy hydraulic cutterhead dredge at Mare Island was monitored during this study.

Trailing Suction Hopper Dredge. The hopper dredge shown in photograph 3, is the only one of the three dredges which is self-propelled. The dredge is an ocean-going vessel designed to hydraulically lift bottom sediments, collect and concentrate the solids in hoppers and transport the sediments to the disposal site. Hopper dredges are primarily used to maintain harbor entrances, channels where rough water makes other methods impractical or where ship traffic requires minimum interference with navigation.

The principal components of the hopper dredge are dragarms, centrifugal pumps, hoppers, propulsion and navigation systems. The most common configuration of the vessel is equipped with port and starboard dragarms or trailing suction pipes. The draghead is used to cut in compacted sediments. In soft sediments the draghead sinks into the bottom and is maintained at a depth to sustain suction to maximize the lifting of sediments. Each suction pipe enters the hull through a 90 degree fitting which swivels allowing vertical control of the dragarm. The dredged sediment is moved through pumps and discharged into the vessel's hoppers as a mud-water slurry. After the hoppers have been filled initially, pumping continues for a period to displace water and increase the density of the sediment for an economic load. As a result of the additional pumping, excess sediment-laden water overflows the hoppers and discharges behind the dredge. Upon reaching an economic load the vessel leaves the dredging area for the disposal site where the sediment is released through the bottom of the vessel into deep water. Some hopper dredges also have direct pumpout capability for pumping the sediment from the hoppers to shore disposal areas. The chief limitation



Trailing Suction Hopper Dredge

of the hopper dredge is the excavation time lost while in transit between the dredging area and the disposal site. The chief advantages is its ability to operate in rough, open waters, high production rate and minimum obstruction of channels. During this study the Corps hopper dredges BIDDLE (single 3,000 cubic yard hopper) and HARDING (twin 1,300 cubic yard hoppers) were monitored.

Further descriptions and discussions of these pieces of equipment can be found in deKoning (1968), Cable (1969), Huston (1973) and Mohr (1974). A discussion of equipment capacities is presented in Appendix J, Land Disposal.

Characteristics Of Bay Sediments

With the exception of the sandy sediments associated with the San Francisco Bar Channel, Southhampton Shoal, Pinole Shoal and Suisun Bay, maintenance dredging operations in San Francisco Bay move "Bay mud". Bay mud consists of soft, plastic, black-to-grey silty clay or clayey silt with minor organic material and clayey fine-grained sand which has been deposited in the Bay largely by flocculation. Flocculation is the process whereby the chemistry of the salt water causes suspended clay and colloidal particles to aggregate, and then settle out of the water column. A typical comparison of the actual grain size (dispersed) versus the effective grain size in the estuarine system (non-dispersed) is shown in Figure 3.

Bay mud tends to flow and has very little bearing strength. It is easily resuspended by wind-wave action, freshet and tidal currents. These characteristics of Bay mud result in a very dynamic system with sediment recirculation through scoured channels and on-and-off extensive mudflats. The properties of Bay mud can be explained by its high water content and low in-place density. Table 3 gives typical ranges of some of the physical properties of Bay sediments. The data in the table is based on single samples and does not necessarily represent the project areas as a whole.

PARTICLE SIZE DISTRIBUTION OF DISPERSED VERSUS NON-DISPERSED SAMPLES

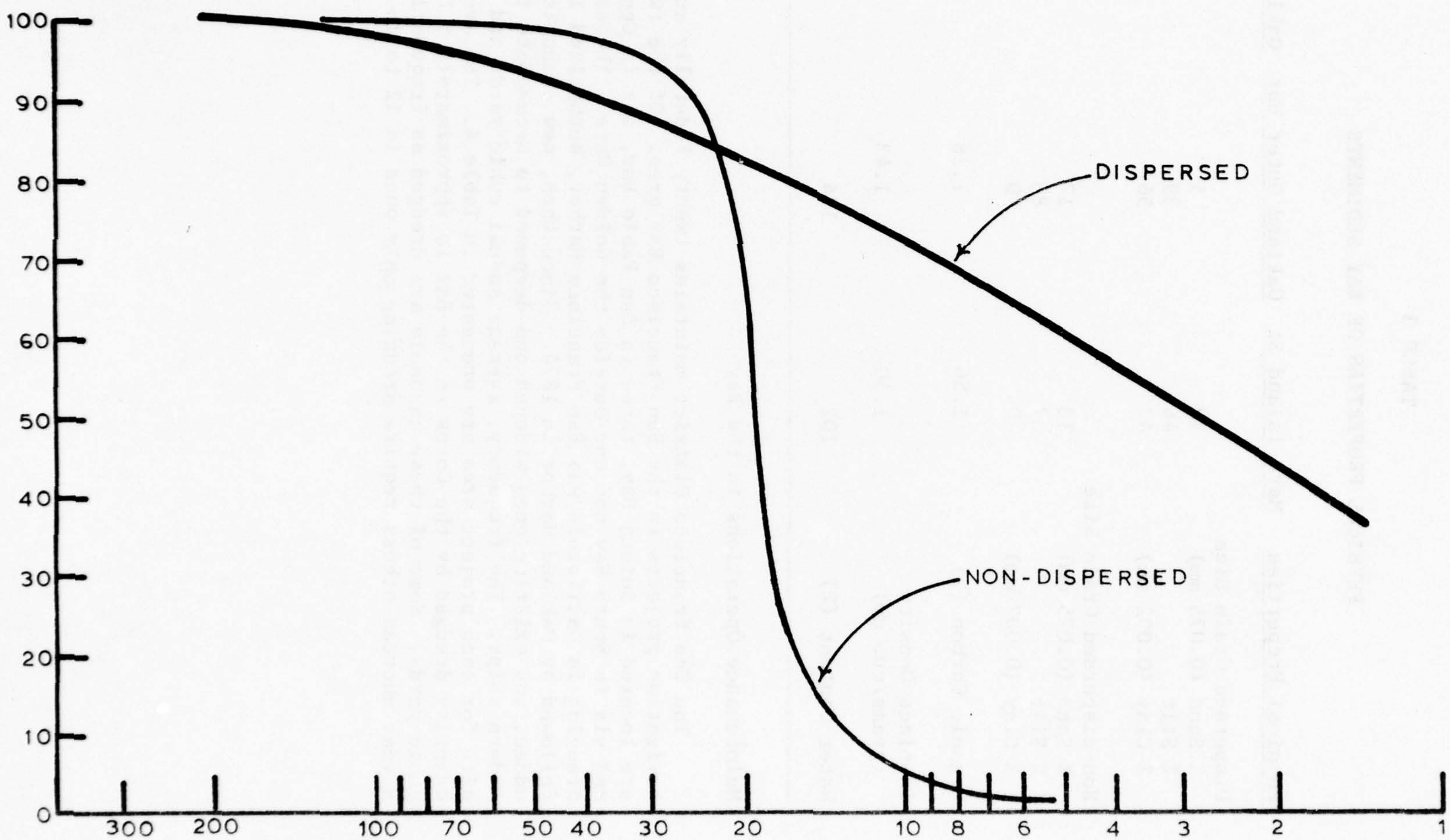


FIGURE 3

TABLE 3

PHYSICAL PROPERTIES OF BAY SEDIMENTS

Physical Properties	Mare Island St	Oakland Outer Hbr	Oakland Inner Hbr
Dispersed Grain Size			
% Sand (0.075 mm)	12	5	15
% Silt	46	39	37
% Clay (0.002 mm)	42	56	48
Non-dispersed Grain Size			
% Sand (0.075 mm)	13	17	20
% Silt	87	83	75
% Clay (0.002 mm)	0	0	5
Organic Carbon (%)	1.56	1.28	1.62
In-place Density (grams/cu. cm)	1.30	1.43	1.28
Water Content (%)	102	124	126

Maintenance Operations in the Bay

The San Francisco District maintains twenty Federally authorized navigation projects in the San Francisco Bay area. Of the twenty, four are located in Suisun Bay, three in San Pablo Bay, six in Central Bay and six in South Bay and one outside the Golden Gate. The earliest dredging in California was San Francisco Harbor, authorized in 1868, followed by Oakland Harbor in 1874. Since then, new channels have been added, and existing ones widened and deepened to accomodate larger, more modern ships. The frequency, average annual cubic yards and disposal site for each project area are presented in Table 4. The average annual quantity dredged by the Corps in the Bay is approximately 5.8 million cubic yards. Some of these channels are dredged as frequently as twice a year whereas others require dredging only once in 12 to 16 years.

TABLE 4

Corps Maintenance Dredging Projects In San Francisco Bay

Location	Frequency (years)	Disposal Site	Average Annual Quantity (1000 cubic yards)
Suisun Bay			
Suisun Bay Channel	1	Suisun Bay	220
Suisun (Slough) Channel	2-3	Land	72
New York Slough	3-5	Land	4
San Pablo Bay			
Mare Island Strait & San Pablo Bay Channel	0.5	Carquinez Straits	2,500
	2	San Pablo Bay	324
San Rafael Creek	6-8	Alcatraz	34
Petaluma River	12	Land	33
Central Bay			
Richmond Harbor	1	Alcatraz	480
Point Molate (Navy)	2-3	Alcatraz	91
MOTBA East (Navy)	3	Alcatraz	40
Sausalito Operations Base	3-4	Alcatraz	26
MOTBA North (Military)	Indefinite	Alcatraz	10
Horseshoe Cove (Army)	Indefinite	Alcatraz	1
South Bay			
Oakland Harbor			
Oakland Outer Harbor	1	Alcatraz	300
Oakland Inner Harbor	1	Alcatraz	350
Redwood City Harbor	1	Land	325
Alameda NAS (Navy)	1	Alcatraz	900
NSC - Oakland (Navy)	2-3	Alcatraz	50
San Leandro Marina	5-6	Land	42
Gov. Island (Coast Guard)	5-10	Alcatraz	1
Ocean			
San Francisco Main Ship Channel	1	San Francisco Bar	1,000

Before 1972, aquatic disposal in the Bay occurred just about anywhere, dictated primarily by economics. In May 1972, in order to regulate indiscriminate dumping, the Corps established five aquatic disposal sites in the Bay which were to be used for all aquatic disposal of dredged material in the Bay. Subsequently, two additional sites were eliminated and one site in Suisun Bay was added. In addition to its own maintenance dredging projects, the U.S. Army Corps of Engineers issues permits to various private entities, port authorities and other agencies which perform their own maintenance dredging. During 1973-1975 period, 0.1 million cubic yards (mcy) of maintenance material in Suisun Bay, 1.1 mcy in San Pablo Bay, 3.5 mcy in Central Bay and 0.4 mcy in South Bay were dredged under permits.

Impact Identification By Others

Relatively few studies of environmental effects were conducted until the last several years. Most of those studies emphasized physical water quality and direct, physical biological impacts associated with operations. The chemical impacts were neglected until recently because of the lack of a basic understanding of aquatic and sediment chemistry. Publications by Horne (1969) and Stumm and Morgan (1970) on aquatic chemistry and by Lee (1970) on interfacial processes provided the foundation from which comprehensive investigations are just now beginning to advance chemical knowledge.

The results of some of the more pertinent investigations describing physical water quality impacts and observed environmental affects are summarized below.

Brown and Clark (1968) investigated the effects of dredging operations on the dissolved oxygen concentration in Arthur Kill, New York. The oxygen level was reduced between 16-83% below normal. They concluded that resuspension of anaerobic bottom sediments in a tidal waterway causes significant reductions in dissolved oxygen concentration in the water.

The Chesapeake Biological Laboratory (1970) conducted studies of the gross physical and biological effects of overboard spoil disposal in upper Chesapeake Bay. Turbidity increased over an area of 4 to 5 square kilometers around the disposal site but was within range of natural variation. Suspended sediments were carried a maximum of about 5000 meters from the discharge point and virtually disappeared within two hours. The sediments deposited to a depth of at least 0.3 meter over an area at least five times as large as the defined disposal site. No gross effects were observed on phytoplankton primary productivity, zooplankton, fish eggs or larvae or fish.

Gordon et al (1972) investigated the environmental consequences of dredge spoil disposal in Central Long Island Sound. They concluded that clamshell dredging produced turbidity within a few meters of the dredge site equal to a force 4 onshore wind. The corresponding suspended sediment concentration was 150 mg/cm^2 or 15g/1.

Gordon (1973) described a plume of turbid water down-current from a clamshell operation in New Haven Harbor, Connecticut. His measurements showed that 2.5 percent of the silt lifted by the dredge was lost to the surrounding water. The resultant siltation rate on the flats adjacent to the operation was 0.5 mm/day. Siltation became immeasurable at about 800 yards downstream of the dredge. He concluded that at distances greater than 500 yards downstream and 100 yards across-stream the siltation due to the dredging is small compared to that caused by typical winter storms.

Gordon (1974) found from turbidity measurements that 99 percent of a non-cohesive material of high silt and clay was transported to the bottom as a high speed jet. Lateral spread of the jet was about 30 percent. Its impact with the bottom produced an outward spreading density current. The density surge carried less than 18 percent of the dredged material outside of a circle of 30 meters in radius and essentially none beyond about 120 meters. The residual turbidity in the water column contains less than one percent of the material discharged. This settles at the fall velocity of individual particles.

Martin and Yentsch (1973) evaluated the effects of dredging on water quality and nutrient chemistry in the Annisquam Waterway, New England. During active dredging, light transmission decreased from 78 percent at the upstream station to 53 percent at the dredging site. However, light intensities were observed to return to normal at a distance of 400 meters downstream. If the dredging and disposal operations caused increased levels of nutrients, the latter were masked by natural fluctuations in the study. The authors emphasize that this is not to say that no actual enrichment took place, but only that within the limits of the study, no detectable change could be attributed to dredging.

Masch and Espey (1967) studied shell dredging in Galveston Bay, Texas. They found that shell dredges resuspended considerable quantities of sediment which formed density layers near the bottom. These density (or fluff) layers were caused when fine sediment flocculated to concentrations greater than 10g/1. The movement of layers was found to be controlled by gravity and were capable of moving in directions other than indicated by either bottom or surface currents. Layers seemed to consolidate at about 175g/1.

Maurer et al (1974) studied the effects of hydraulic dredging and spoil disposal near the mouth of the Delaware Bay. Secchi disc readings made in the study area indicated that the change in suspended sediment concentration following dredging and dumping was insignificant when compared to the natural load. The operation caused reductions of dissolved oxygen from approximately 94 percent to 52 percent mean oxygen saturation.

May (1973) studied hydraulic channel and shell dredging and open water spoil disposal in Alabama estuaries. He found that almost all of the sediment discharged by dredges settles very quickly and is transported by gravity along the bottom as a separate flocculated density layer. His investigations indicated that both organic and inorganic constituents in these effluent sediments remain largely adsorbed or insoluble under aerobic dredging conditions in the presence of high clay concentrations and the common ions of brackish water. Consequently, he did not believe that potentially deleterious components were available for biological uptake. He observed that suspended solids were temporarily increased to high levels over a limited area, but beyond 1,600 feet did not exceed levels measured during windy conditions.

Slotta et al (1973) working in Coos Bay, Oregon, with the hopper dredge HARDING recorded dissolved oxygen reductions on two of four occasions at the disposal site. Both reductions occurred near the bottom, downstream of the dredge a few minutes after disposal was completed. The first drop went from an ambient 9 ppm to 3.11 ppm and continued to decrease to 1.78 ppm. In the second reduction the dissolved oxygen level initially decreased to 2.18 ppm with subsequent readings of 1.36 ppm, 2.36 ppm and 4.54 ppm. The reduction lasted at least 30 minutes (the period readings were taken).

The U.S. Army Corps of Engineers (1967) conducted a water quality investigation during dredging of highly polluted Chicksaw Creek, a tributary of the Mobile River, Alabama. They found dissolved oxygen was depressed in the recently dredged area 100 feet behind the pipeline dredge more than it was in an area 100 feet ahead of the dredge. This was described as temporary and water quality actually improved following dredging. With the exception of increased suspended solids levels, no other parameter studied appeared to change during the dredging operation.

The U.S. Army Corps of Engineers (1969) studied the problems associated with dredging and water quality in the Great Lakes. In Calumet River a clamshell operation was found to have little effect on water quality except for turbidity which doubled (20 Jackson Turbidity Units, JTU, to 40) downstream of the dredge. Sampling during dredging in Cleveland Harbor showed short-term adverse effects on water quality. Dissolved oxygen in the vicinity of the hopper dredge decreased as much as 25 percent. In the dumping area, depressions up to 35 percent of the

oxygen level were measured. Suspended solids also increased substantially. Studies in the Rouge River indicated significant increases in suspended solids, volatile suspended solids, chemical and biological oxygen demand, total phosphorus, and iron in the immediate area of the hopper dredge. Overflow from the hopper bins caused the most severe pollution. After passage of the dredge the dissolved oxygen levels decreased with time as long as the material remained in suspension. In the Detroit River near the spoil area, no significant changes in water quality could be attributed to the disposal operation.

Westley et al (1973) evaluated the effects of channel maintenance dredging and disposal of the dredged material on the marine environment in Southern Puget Sound, Washington. The investigators compared the impact of aquatic disposal by both barge and pipeline operation. Observations of dumping by barges indicated that the disposed material remained relatively intact as it fell to the bottom. Dispersion of silt on the bottom and in the water around the barge dump site was limited. In contrast to barge dumping, pipeline disposal resulted in increased levels of silt in the water distributed over a large area. The observations indicated most of this discharged material settled rapidly to the bottom. Water quality observations indicated a minor decrease in oxygen and minor increase in BOD associated with pipeline dredging. There did not seem to be any significant effect on water quality from the barge disposal.

Windom (1972) conducted laboratory and field investigations to determine the environmental effects of dredging operations on water quality. He found that in relatively unpolluted areas, dredging had no effect on water quality whether the spoils were placed in diked or undiked areas. In polluted marine environments, water quality degradation by dredging operations showed no simple relation to the composition of the dredged sediments, and thus dredging of polluted sediments did not necessarily impair estuarine water quality. He concluded that the effects are dependent on the characteristics of the area to be dredged.

Windom (1974) investigated the processes responsible for water quality changes during pipeline dredging in marine environments. He found that water quality changes during dredging operations cannot be predicted on the basis of simple bulk chemical analyses of the sediment to be dredged. His studies indicated that there can be significant variations in the quality of water leaving a diked disposal area depending on its retention time. There was no clear indication that a long retention time improved the quality of the return water from a diked disposal site. Dynamic analytical techniques appeared to provide a possibility for predicting the water quality changes that might occur during a dredging operation.

STUDIES CONDUCTED

The principle thrust of the Dredge Disposal Study was to assess the potential environmental effects of dredging and disposal in San Francisco Bay. An integral part of the assessment was the determination of how these operations influence Bay water quality for future assessment of potential biological and chemical effects. In 1973 investigations were initated to define the effects of dredging activities on ambient water conditions. The program began with a generalized examination and evaluation of the affects of both dredging and disposal operations on six water quality parameters. These included conductivity/salinity, temperature, pH, dissolved oxygen and turbidity. As the program progressed specific parameters were found to deserve special attention both during the dredging and during the disposal process. During the dredging operation turbidity and suspended solids loading from hopper dredge overflow merited quantification as did the dimensions of the plume it generated. Turbidity, suspended solids and dissolved oxygen aberrant concentrations during the initial monitoring program were of sufficient magnitude to deserve more intense examination during disposal operations. The initial general investigations are described in the following section on Routine Monitoring. The studies emphasizing a particular parameter are separated into those pertaining to dredging (Dredging Special Studies) and those pertaining to disposal (Disposal Special Studies).

Routine Monitoring

The routine monitoring program was conducted during the Corps' 1972-1974 maintenance operation with the trailing suction hopper dredge HARDING. The program was broken into two tasks. First, monitoring was performed to obtain background levels of the six parameters. Second, during dredging and disposal operations the parameters were monitored to ascertain the degree and duration of variations in water quality. The areas monitored included the authorized channels in Mare Island Strait, Pinole Shoal, Richmond Harbor, and Oakland Harbor and three disposal areas at Carquinez Straits, San Pablo Bay and Alcatraz. The locations of channels and disposal areas in the Bay are shown in Figure 4.

Equipment. The monitoring program was conducted with the survey vessel GRIZZLY. The GRIZZLY is a converted tug (ST-3001), fifty feet in length with a fourteen-foot beam and five-foot draft (see photograph 4). Depth was determined with a Ross Fine-Line recording fathometer. Positioning was determined using a combination of readings from a Cubic Autotape, Model MD40 and sextants. Instrument packages were raised and lowered using a 1,500 pound hydraulic winch on the port side of the vessel.

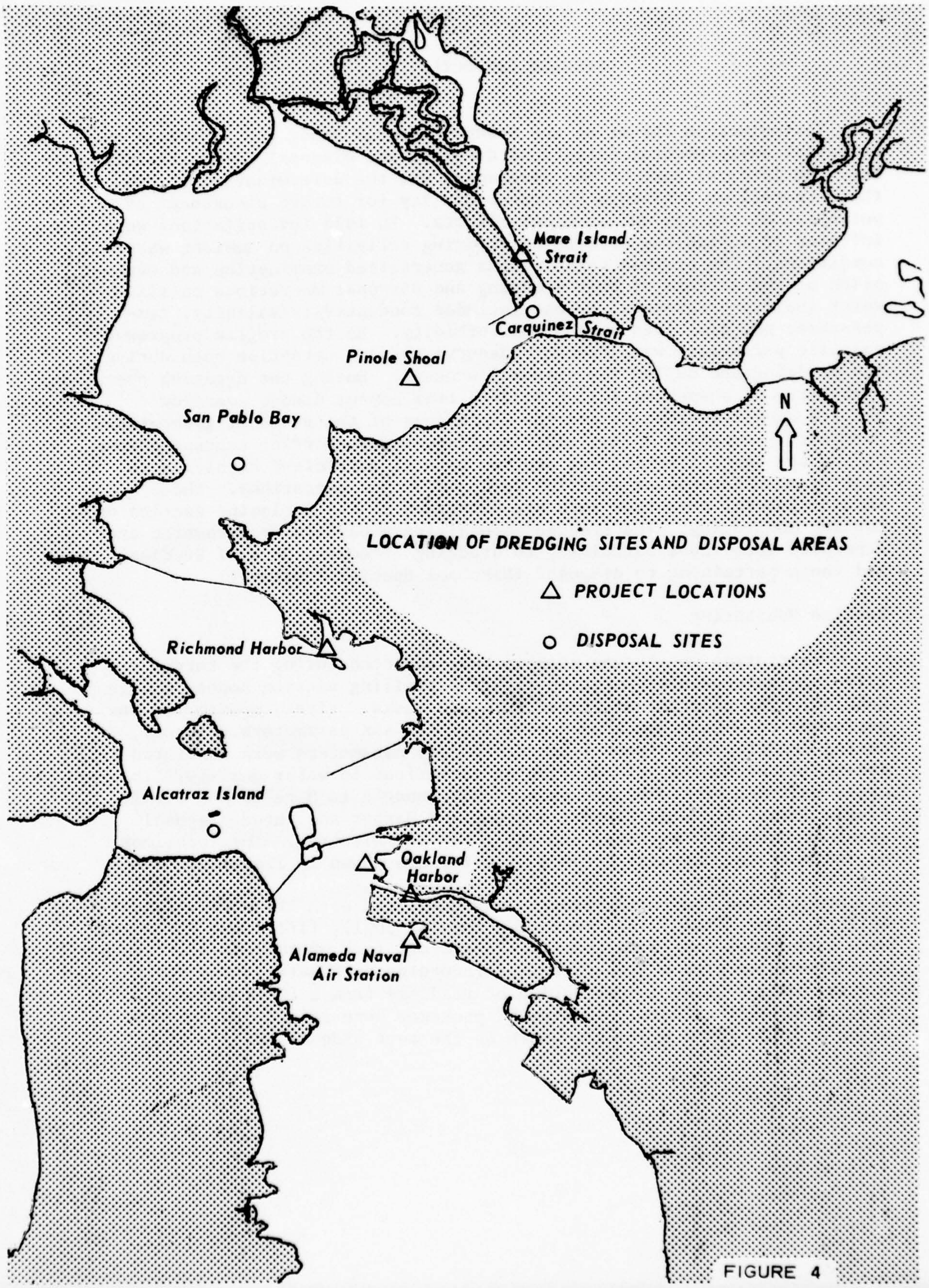

Mare Island Strait
Carquinez Strait
Pinole Shoal
San Pablo Bay
N
LOCATION OF DREDGING SITES AND DISPOSAL AREAS
PROJECT LOCATIONS
DISPOSAL SITES
Richmond Harbor
Alcatraz Island
Oakland Harbor
Alameda Naval Air Station

FIGURE 4

Survey Vessel GRIZZLY

PHOTOGRAPH 4

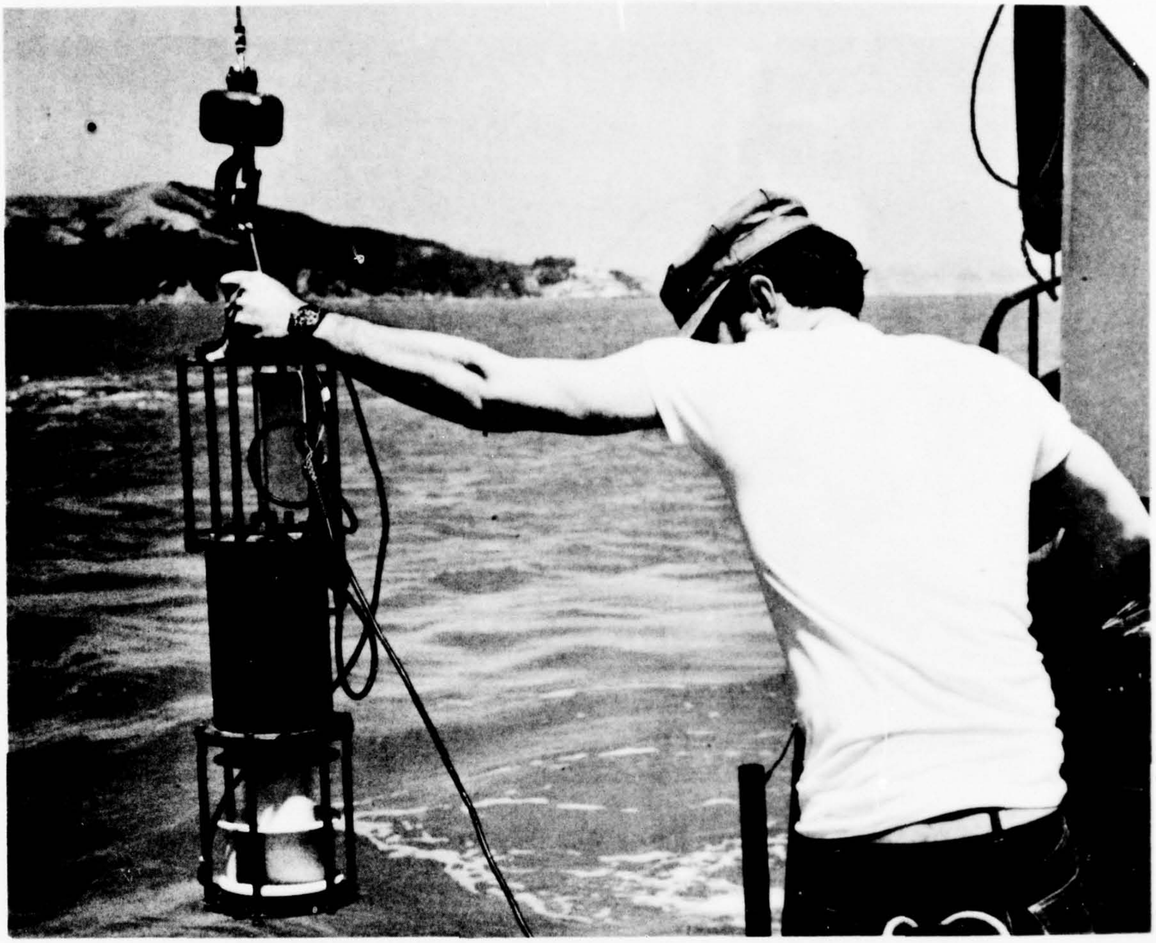
Current velocity and direction were measured with one of two different current meters, depending on hydrographic conditions. A Bendix Q-9 meter was used in applications wherever wave particle velocities were small. It employs a Savionius rotor speed sensor and orients itself by means of an internal magnetic compass (see photograph 5). Measurements were transmitted by hard wire to a Bendix S-232 readout (see photograh 6). A Bendix Q-15 ducted-impeller meter was used to measure currents in the presence of waves. Measurements were logged on a Bendix S-235 in-situ analog recorder.

Water quality monitoring was performed with an InterOceans water quality survey system (see photograph 7), Model 500, with digital and analog readout, Model 514A (see photograph 8). The instrument gives continuous readout of temperature, dissolved oxygen, turbidity, pH, conductivity, salinity and depth. The instruments were calibrated with the appropriate equipment or standard solutions at the beginning of each monitoring. The dissolved oxygen probe was calibrated and continuously checked by Wrinkler Titrations (see photograph 9). Samples for suspended solids were collected by both a surface pumping system and a Van Dorn 3-liter water bottle (see photograph 10).

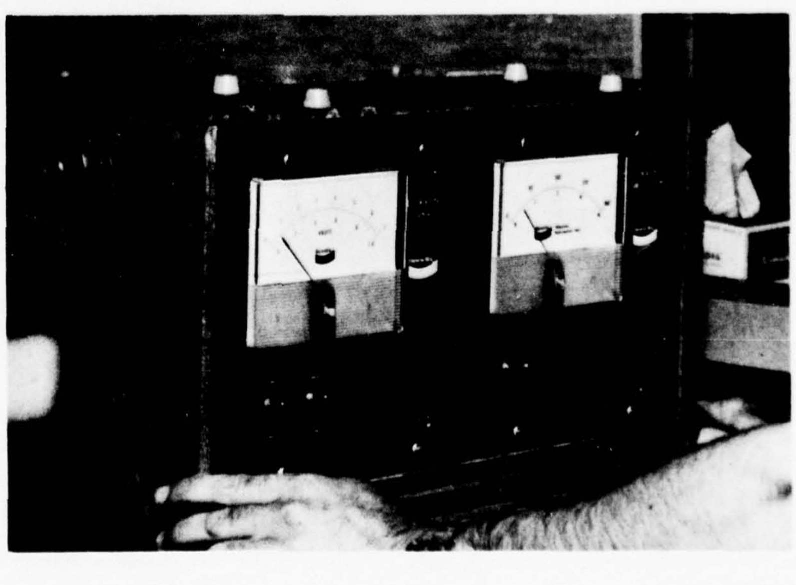
Procedures. From 1971 to fall 1972 various pieces of monitoring equipment and techniques were tested and evaluated. The equipment and techniques were selected, and the monitoring program commenced with 1972-73 maintenance operations. The locations of fixed stations for each project and disposal site are shown in Inclosure 3. The procedures used were consistent for each of the areas.

Prior to each operation a mid-channel transect was laid out in the area to be dredged. At the same time a transect was laid out through the appropriate disposal site. Each transect was broken into four or five intervals with a monitoring station situated at the junction between intervals (see Inclosure 3 for specific locations). Monitoring at each station was conducted utilizing vertical profiles with readings taken at 1, 2.5, 5, 7.5 and 10 meter depths. Discrete measurements were taken at each depth using the Inter-Oceans survey system to monitor changes in dissolved oxygen, pH, turbidity (in terms of Formazine Turbidity Units (FTU) and percent transmission), temperature, conductivity and salinity. Discrete readings of current velocity and direction were taken prior to each profile when the Bendix Q-9 was used. When the Bendix Q-15 was used a continous record of current velocity and direction was obtained.

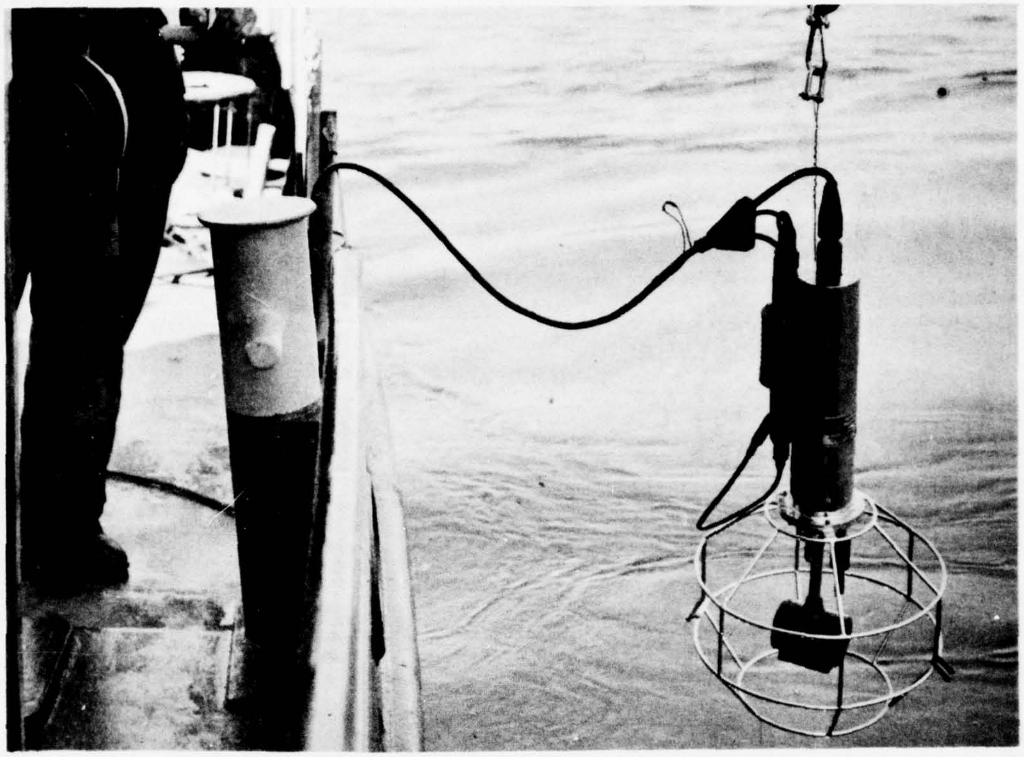
The monitoring performed during the dredging operation was broken into three tasks. First, prior to dredging, monitoring was conducted at each selected station to obtain background measurements. Background monitoring commonly occurred just preceding commencement of operations but never more than five working days before dredging began. Second,



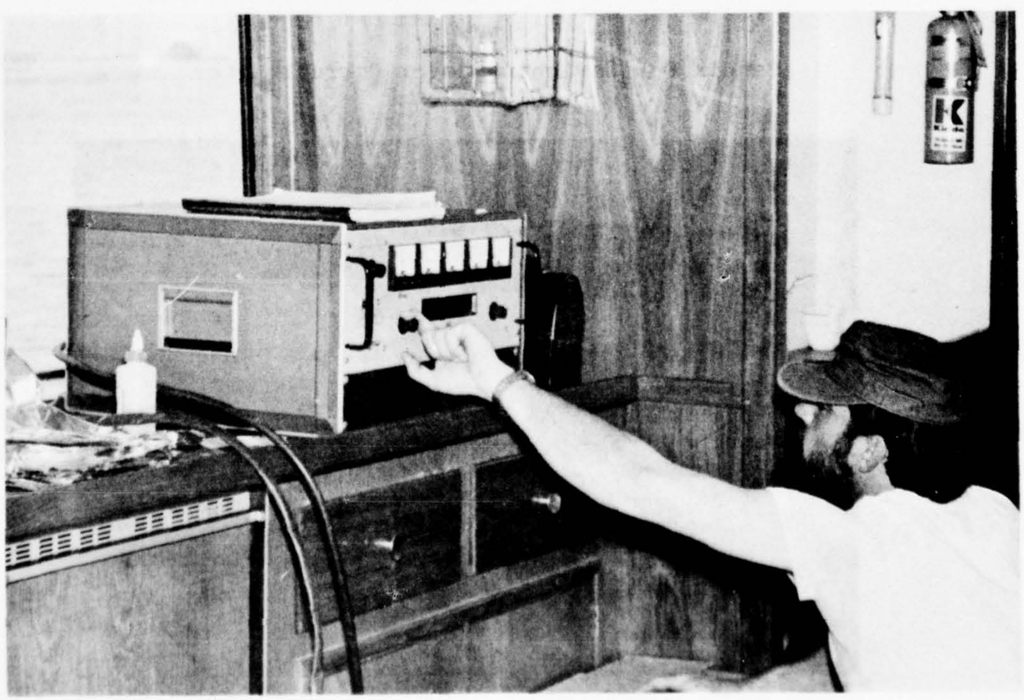
Bendix Q-9 Savionius Rotor Current Meter PHOTOGRAPH 5



Bendix S-232 Hard Wire Readout PHOTOGRAPH 6

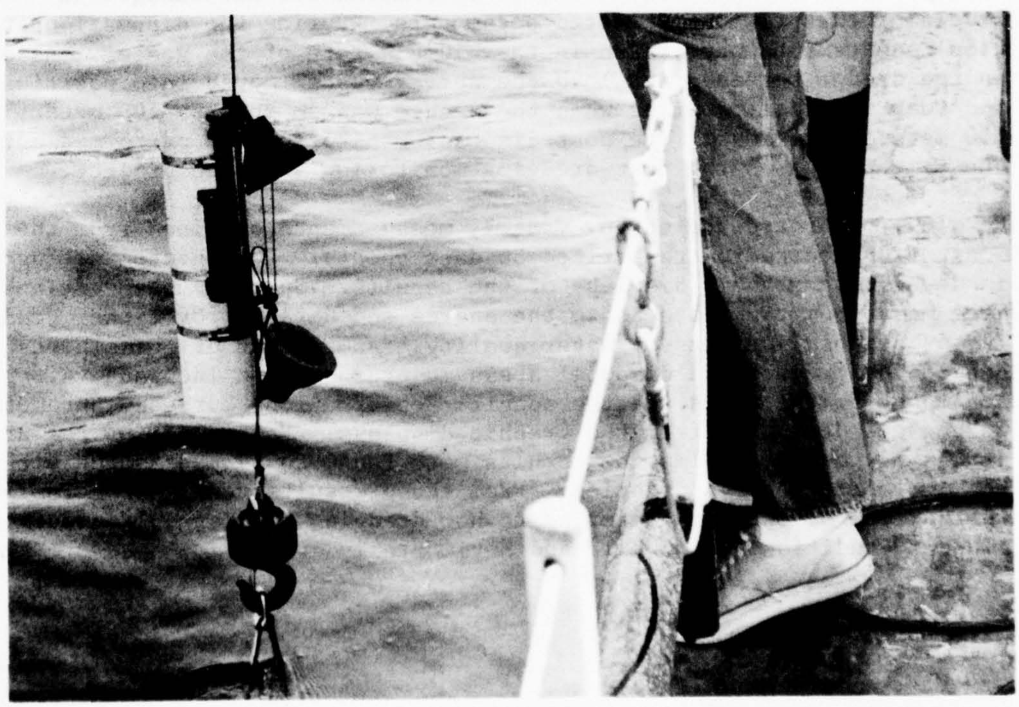


Inter-Oceans Water Quality Probe, Model 500 PHOTOGRAPH 7



Inter-Oceans Digital and Analog Readout, Model 514A PHOTOGRAPH 8

Water Sample Analysis PHOTOGRAPH 9



Van Dorn 3-Liter Water Bottle PHOTOGRAPH 10

during the dredging operations measurements were taken at 50 meters, 100 meters, and 400 meters astern of the centerline of the dredge. The fixed stations utilized during the presurvey for background levels served as general monitoring site locations but were not rigidly adhered to as the only positions which could be monitored. During the duration of the project monitoring was conducted at a minimum of once a week. Water quality measurements were obtained during flood, slack and ebb tides to obtain a full range of tidal conditions. During the period when dredging operations occurred, the survey vessel would wait on station until the dredge passed, then would pull in astern, avoiding propellor wash and turbulence which might damage the equipment. Once on station (at approximately 50 meters astern of the dredge) the crew would lower the monitoring probe to previously selected depths, the deepest reading depending on water column depth. Measurements of the six parameters were taken at each of the prescribed depths. Following completion of the profile the probe was raised to the surface. Then the survey vessel waited until the hopper dredge moved 100 meters from the station. At that time the monitoring sequence was again initiated. This sequence was repeated again at 400 meters. Third, after two weeks and within four weeks after the completion of the dredging operation, background measurements were again obtained at each of the fixed stations within the project area. The techniques were the same as those used during the predredging survey.

Monitoring at the disposal site was conducted in much the same manner as was the monitoring in the dredging area. These stations were surveyed prior to the initiation of operations for the background levels of the previously listed parameters. During the disposal operation measurements were taken in the plume astern of the vessel. As soon as the dredge released its load the survey vessel moved into position and took vertical profiles when the dredge was 50 meters, 100 meters and 400 meters upcurrent. The post-disposal monitoring was performed during the same period as the post-dredging monitoring for each project.

Results. On board the survey vessel, measurements obtained from the monitoring gear were transcribed on data sheets. The sheets were used in developing graphic displays of the results. Specific observations were made from the plots as to the degree and duration of either dredging or disposal affects on water quality. An example of these plots for one of the project and disposal areas is presented in Inclosure 4. Accompanying the plots are the specific observations for each parameter which were developed from the graphic displays. Regardless of the area in the Bay being studied the results were found to be consistent within the two operational categories. From these results general conclusions were drawn for each parameter as to how dredging or disposal influenced ambient conditions vertically and horizontally.

In general, the dredging operation did not exert a detectable influence on the background conductivity/salinity, either vertically or horizontally. As the distance from the dredge increased, there was no apparent change in the conductivity/salinity. Infrequently, aberrant readings were recorded because either high density (high conductivity/salinity) water, pumped from the bottom, overflowed into the lower density (lower conductivity/salinity) surface water, or the vessels' movement disturbed existing stratification.

Temperature did not vary significantly as a result of the dredging operation. Neither vertical nor horizontal readings showed detectable changes.

The hydrogen ion concentration (pH) infrequently deviated slightly astern of the dredge. Changes were usually less than one-half unit and returned to background levels within 100 meters downstream of the dredge. These variations were not consistent vertically. Occasionally, they occurred in the surface waters, and at other times they occurred in the bottom water. The mid-water column typically was not influenced when aberrant readings were found in the surface or bottom water.

The ambient dissolved oxygen concentration in the Bay is between 8 and 9 parts per million (ppm). During dredging operations recordings showed dissolved oxygen reductions at the surface of 2 ppm. The oxygen consuming substances causing the reduction generally were satisfied or dispersed within 100 meters downstream of the dredge. Ambient levels were re-established. Duration was approximately two minutes. Reductions in the lower water column were as much as 4 ppm at the stern of the dredge. The intensity of the depression decreased with increasing distance from the dredge. Ambient oxygen concentrations typically had returned within 400 meters downstream after an approximate duration of eight minutes. Dissolved oxygen depressions were observed in less than a quarter of the monitoring periods.

Turbidity plumes, measured in percent transmission and Formazine Turbidity Units (FTU), occurred in both the upper and lower water column. A bottom plume resulted from perturbation of sediments by the dragheads, by vessel hull and by propeller wash. The plume extended approximately three meters off the bottom. It did not decrease significantly within 400 meters astern of the dredge. During periods of overflow a surface plume was evident. Initially the plume was limited to the upper 2 to 3 meters. As distance from the dredge increased and the particulates at the surface settled through the water column, the two plumes (bottom and surface) merged. After the plumes merged, approximately 100 meters downstream of the dredge, increased turbidity was evident throughout the water column. At 400 meters downstream, the surface and occasionally the mid-waters were partially cleared. Clearing of the water column is dependent on salinity and current velocities.

The magnitude of the optical readings between the different project areas varied significantly. In Mare Island Strait, both background readings and readings taken during dredging could exceed the measuring capability of the instrument. Readings of zero percent transmission and 200 plus FTU were common (limits of the instrument). In other portions of the Bay, the same dredge working in similar material recorded readings of 20 percent transmission and 150 FTU. This variability indicated that even under similar conditions any direct comparison of turbidity measurements between project areas was hazardous.

Monitoring during disposal operations showed that conductivity/salinity were not influenced detectably either horizontally or vertically. Neither temperature nor pH showed significant change during disposal.

Dissolved oxygen concentrations could be reduced throughout the water column. Reductions were recorded approximately sixty percent of the time. The dissolved oxygen level in the upper water column (0 to 5 meters) decreased as much as 2 ppm for two to three minutes. This depression generally was undetectable beyond 400 meters of the release point.

Reductions in the lower water column occurred more frequently than reductions in the upper waters. At depths greater than five meters the dissolved oxygen concentration was depressed as much as 6 ppm. It did not recovery fully to ambient levels during the monitoring period (approximately 8 minutes). Because of the reduced nature of Bay muds there is a potential of a dissolved oxygen decrease with every release.

Disposal operations caused elevated turbidity levels throughout the water column. As with dissolved oxygen reductions, turbidity increased with depth. Almost immediately after the material was released, turbidity could increase beyond the instrument's capacity to measure. Typically, the upper and mid-water column were partially cleared at the 400 meter station. The lower water column (10-12 meters) did not clear significantly at the Carquinez Strait Disposal Site (approximately 14 meters deep). At the Alcatraz disposal site, turbidity was most severe several moments after release, with FTU readings exceeding 200 units. Initially turbidity increased in the upper and middle water column. After three to four minutes the turbidity decreased about seventy percent in the upper levels of the water column. There was subsequent reduction in the lower levels. In ten to fifteen minutes the plume was usually dispersed to background levels.

Evaluation. The results of the routine monitoring program indicated that turbidity needed further quantification and evaluation during dredging operations. During disposal operations, both turbidity increases and dissolved oxygen reductions were of sufficient magnitude and

duration to require further quantification and evaluation. In addition, particular emphasis needed to be placed on the aberrant characteristics of these parameters in the bottom portion of the water column. Optical measurements of turbidity were inadequate for proper quantification of particulate loading. Measurements of suspended solids concentration were needed. Optical measurements, however, could be used for rapid profiling if calibration curves could be developed. Such curves would enable the conversion of transmission readings into optical milligrams per liter. These units would be then consistent between different areas.

Dredging Equipment Comparison

The routine monitoring of Corps of Engineer maintenance operations was limited to surveillance of the effects of hopper dredges. A limited survey was conducted of the effects on the water column by operations of a hydraulic cutterhead and of a clamshell dredge. The purposes were to broaden the data base and to determine if different types of dredging equipment cause different resuspension configurations and durations. The hydraulic cutterhead and clamshell dredge, because of their sessile natures, were monitored as point sources. On the other hand, the trailing suction hopper dredge because of its mobility and variability of overflow, was monitored on a time basis instead of a distance basis. Hydraulic cutterhead use is restricted to small marina and channel maintenance in the Bay. The Navy continuously uses a small (18-inch) hydraulic cutterhead to remove shoal material from around the piers and docks at their shipyard facility in Mare Island. This material is disposed in a nearby landfill area. The dredging occurs in water slightly deeper than ten meters. A pre-survey showed there was very little turbidity present in the upper water column. Therefore, survey measurements of suspended solida levels were limited to the bottom waters. Monitoring of suspended solids, turbidity, salinity and currents was performed at 50, 100, and 400 meters downcurrent of the operating dredge at a ten meter depth.

The clamshell dredge is used more commonly than the hydraulic cutterhead in San Francisco Bay. A clamshell with an eighteen cubic yard bucket was monitored during a channel deepening project in Oakland Inner Harbor. Readings were taken prior to and during dredging at depths of 1,5 and 9 meters (channel is little less than ten meters deep) at each of three stations: 50, 100 and 400 meters downcurrent. The parameters measured were the same as those measured during the cutterhead operation.

During hopper dredging operations in Mare Island Strait, these same parameters were monitored at two depths (1 and 10 meters) prior to and through periods of overflow. The overflow period was pushed beyond the

economic load point to obtain data. Usually overflow lasts less than three minutes in Mare Island, but in this case it was continued for nine minutes. Samples were taken at three minute intervals as the dredge continued moving upstream.

Results of the monitoring indicated that, during the dredging operation, all three pieces of equipment caused suspended solids levels to increase above background levels in the lower portion of the water column. This was obviously the result of disturbance of the bottom materials by the cutting device, whether draghead, cutterhead or bucket. Secondary increases occur at the surface with the hopper dredge and clamshell dredge. With the hopper dredge, this was the result of overflow. With the clamshell dredge, it was caused by material being washed from the bucket during the lifting process and when the bucket breaks the water's surface. The data from suspended solids analyses of the water samples are presented in Table 5.

TABLE 5

RESULTS OF SUSPENDED SOLIDS
ANALYSES OF WATER SAMPLES

	MEAN OF SUSPENDED SOLIDS (mg/L)
Pipeline (n=5)*	
10-meter depth background	43
10-meters/50 m. downcurrent	70
10-meters/100 m. downcurrent	56
10-meters/400 m. downcurrent	51
Clamshell (n=3)*	
1-meter depth background	18
1-meter/50 m. downcurrent	78
1-meter/100 m. downcurrent	41
1-meter/400 m. downcurrent	25
5-meter depth background	20
5-meter/50 m. downcurrent	53
5-meter/100 m. downcurrent	58
5-meter/400 m. downcurrent	12
9-meter depth background	22
9-meter/50 m. downcurrent	282
9-meter/100 m. downcurrent	100
9-meter/400 m. downcurrent	39
Hopper (n=3)* - All readings 50 m. downcurrent	
1-meter depth background	182
10-meter depth background	158
1-m. dredging w/o overflow	212
10-m. dredging w/o overflow	227
1-m. dredging begin overflow	364
10-m. dredging begin overflow	252
1-m. dredging overflow (+3 min.)	74
10-m. dredging overflow (+3 min.)	164
1-m. dredging overflow (+6 min.)	355
10-m. dredging overflow (+6 min.)	871
1-m. dredging overflow (+9 min.)	315
10-m. dredging overflow (+9 min.)	387

* "n" is the number of samples used to determine the mean.

Dredging Special Studies

Overflow Quantification. Special studies were conducted to quantify the levels of suspended solids and turbidity associated with the dredging operation. The first of these studies evaluated hopper dredge overflow characteristics during operations in Mare Island Strait and Richmond Inner Harbor. The objectives of the study were, first, to determine the efficiency of the dredge without overflow and with overflow, to and beyond the point of economic load. The second objective was to determine the economic load point, including the number of cubic yards, and the pumping time to reach that point.

During dredging, loading efficiencies were determined by sampling the pump chutes, the hoppers and the overflow spillways throughout the dredging cycle. The purpose was to evaluate the quantity of solids which passes overboard during the overflow period and the quantity that remains in the hopper. The sampling intervals during overflow periods were either two or three minutes, depending on the vessel's mode of operation. Only one hopper was utilized for sampling. Simultaneous samples were obtained from both the pump and the overflow. The samples were obtained over a six week period in Mare Island Strait. During the entire period, overflow was not required for an economic load. The hoppers were intentionally overflowed for the samples, resulting in potentially higher overflow concentrations.

The results are graphically depicted in Figures 5 and 6. Figure 5 relates the volume of solids (settleable matter) to the dredging operation prior to and with overflow. "Average chute" sample is the material being pumped into the hopper. The "average final top of hopper" sample represents the pumped sediment concentration following dilution with the water retained in the hopper. This retained water, about 600 cubic yards prior to overflow, results from the hopper gates not being water tight. It is shown at time zero on Figure 6. The regression curve on Figure 5 was calculated from the "overflow" samples. It indicates that the percent of settlement matter lost in the overflow increases with time until it reaches a hypothetical limit, "average chute." After this limit is exceeded, all sediment loaded is lost in the overflow. The loading curve with the overflow losses are graphed in Figure 6. Initial *in situ* loading of the hopper is about 90% of the pumping rate. Efficiency of the overflow is to decrease the water load due to the remaining 10% and the initial 600 cubic yards. *In situ* channel density of the sediments correlates with 1000 ml/l of settleable solids, about 16% by volume. The graph presents a hypothetical maximum loading time, taking into account the mixing which occurs in the hoppers.

Loading curves were generated from the loading graph and vessel displacement for both Mare Island Strait and Richmond Inner Harbor. They are presented in Figures 7 and 8. Three curves are shown on each figure. The solid line depicts the loading characteristics. The long-dashed line shows the maximum output in cubic yards per cycle-minute;

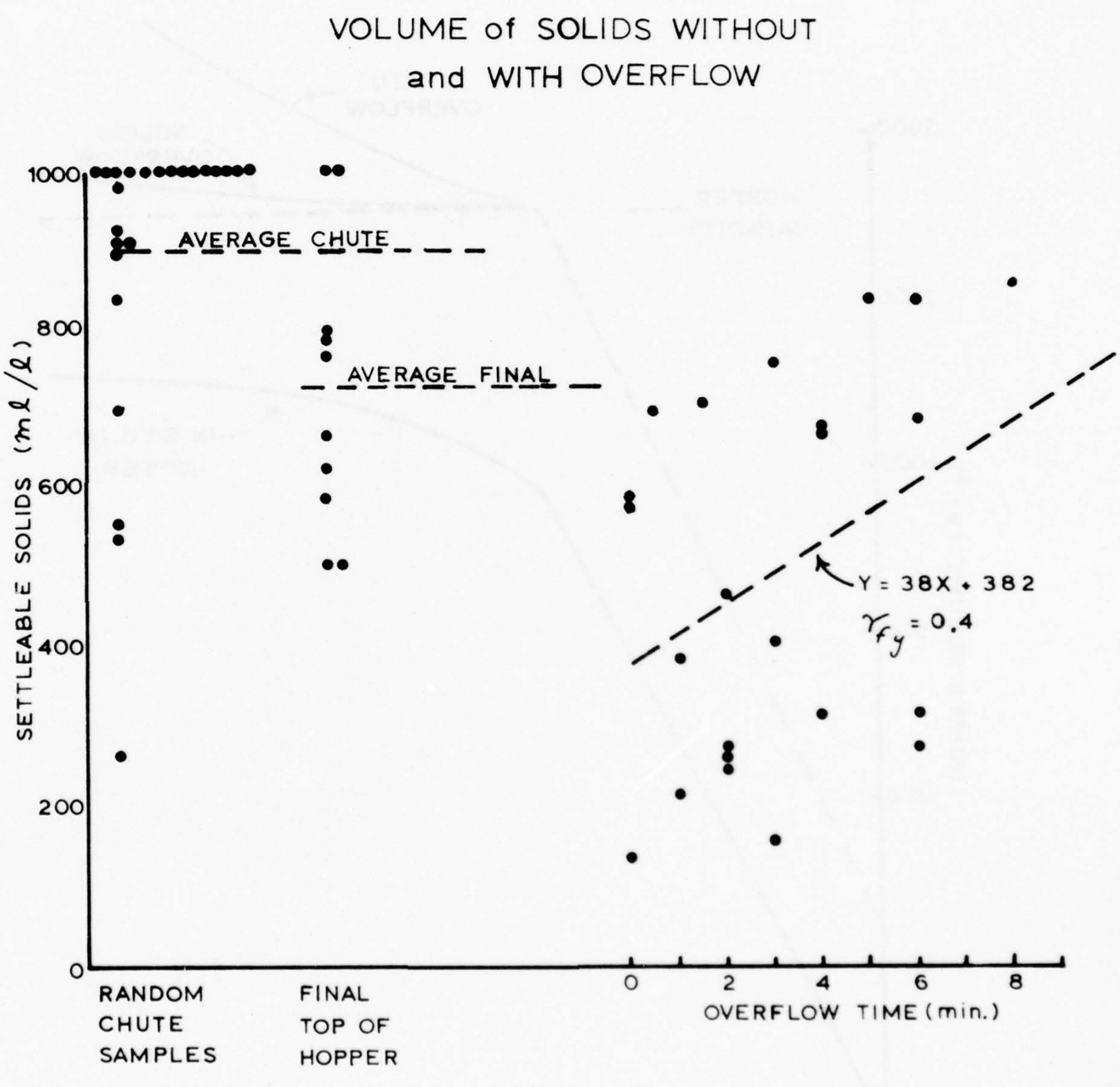

VOLUME of SOLIDS WITHOUT
and WITH OVERFLOW
SETTLEABLE SOLIDS (ml/l)
1000
800
600
400
200
0
AVERAGE CHUTE
AVERAGE FINAL
Y = 38X + 382
r_{fy} = 0.4
RANDOM
CHUTE
SAMPLES
FINAL
TOP OF
HOPPER
0
2
4
6
8
OVERFLOW TIME (min.)

FIGURE 5

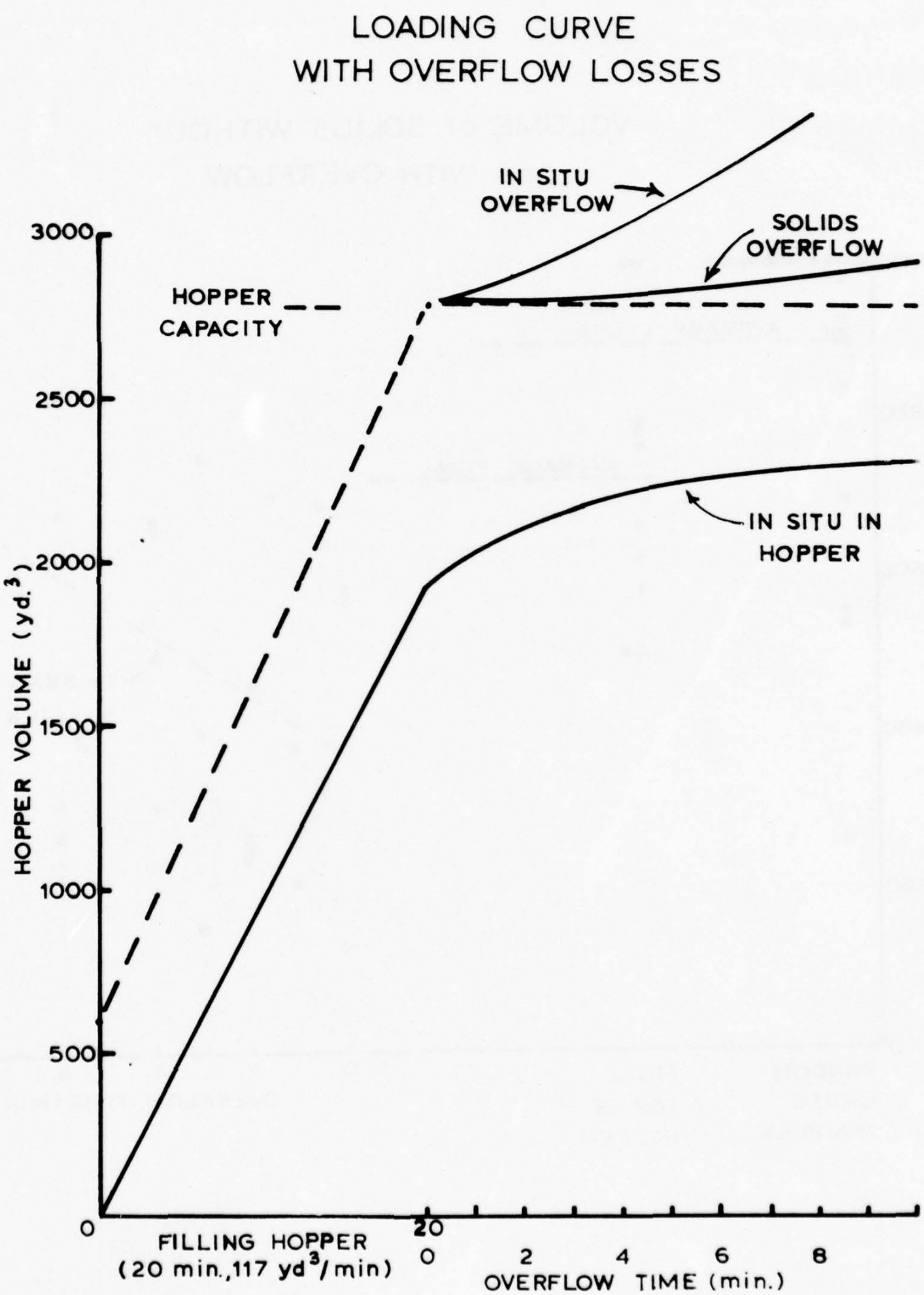
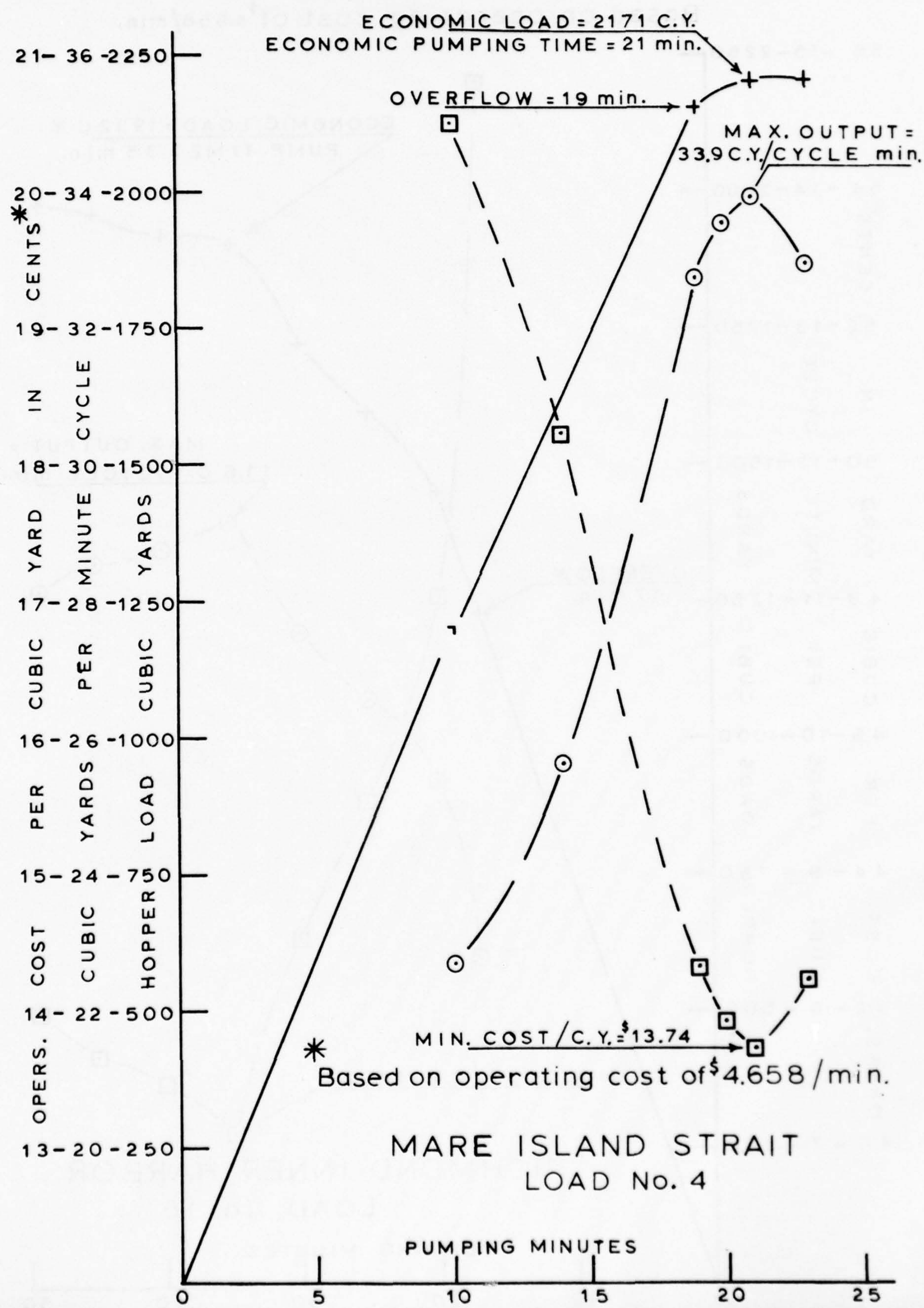
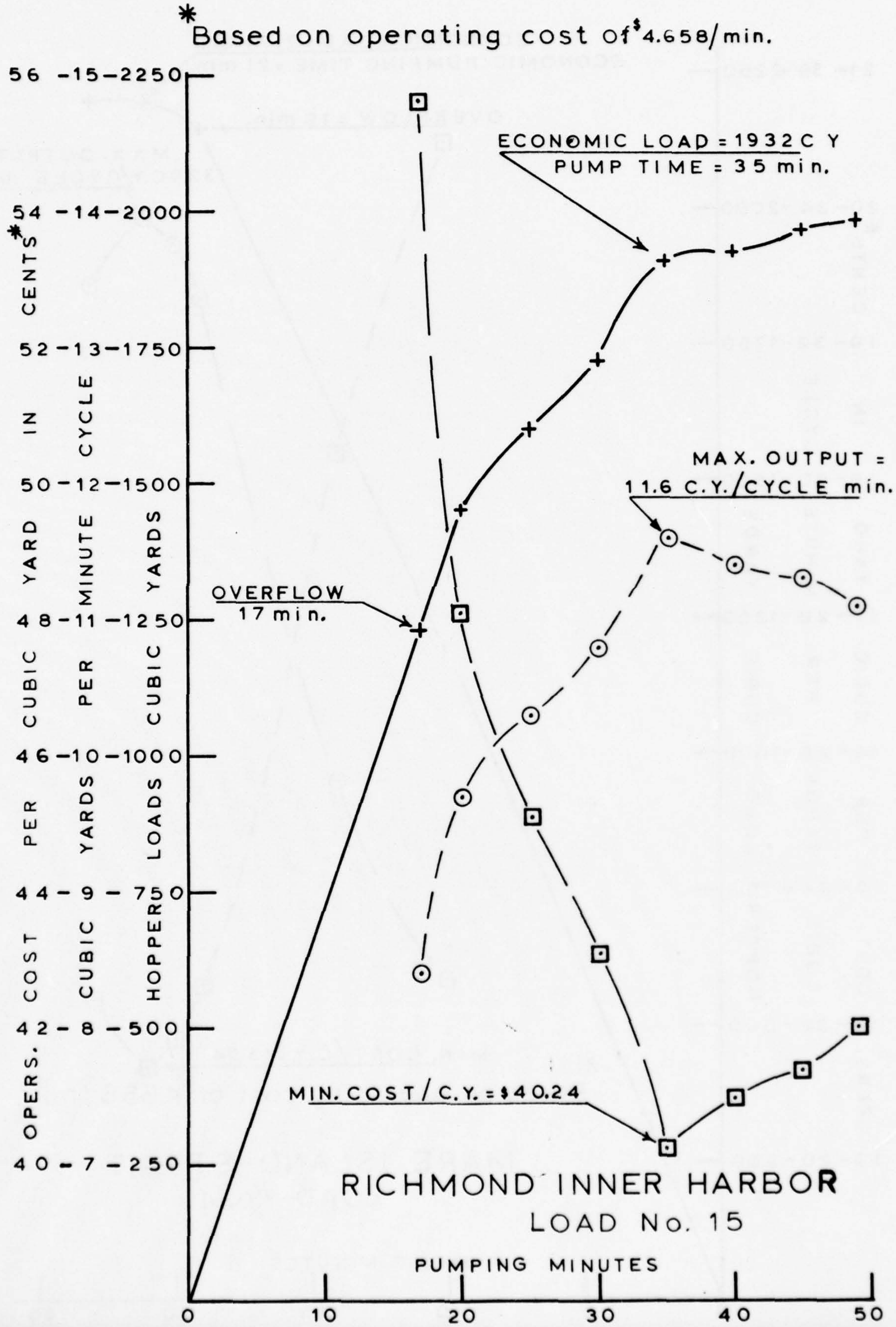

LOADING CURVE
WITH OVERFLOW LOSSES
IN SITU OVERFLOW
SOLIDS OVERFLOW
HOPPER CAPACITY
IN SITU IN HOPPER
HOPPER VOLUME (yd.^{3})
3000
2500
2000
1500
1000
500
0
20
FILLING HOPPER
(20 min., 117 yd^3/min)
0
2
4
6
8
OVERFLOW TIME (min.)

FIGURE 6



MARE ISLAND STRAIT
LOAD No. 4

FIGURE 7



*Based on operating cost of $4.658/min.
56 -15-2250
54 -14-2000
52-13-1750
50-12-1500
48-11-1250
46-10-1000
44-9-750
42-8-500
40-7-250
OPERS. COST PER CUBIC YARD IN CENTS*
CUBIC YARDS PER MINUTE CYCLE
HOPPER LOADS CUBIC YARDS
ECONOMIC LOAD = 1932 C Y
PUMP TIME = 35 min.
MAX. OUTPUT =
11.6 C.Y./CYCLE min.
OVERFLOW
17 min.
MIN. COST / C.Y. = $40.24
RICHMOND INNER HARBOR
LOAD No. 15
PUMPING MINUTES
0
10
20
30
40
50

FIGURE 8

and the short-dashed line indicates the minimum cost per cubic yard. In Mare Island Strait the loading curve broke shortly after overflow was initiated (three minutes). In Richmond Inner Harbor eighteen minutes of overflow was required to reach the economic load. The economic load is the point where the cost is minimum per cubic yard. This is not the maximum load. The difference between the loading time in Mare Island Strait and Richmond Inner Harbor is a function of the shoal configuration, sediment and salinity. Other project areas which differ in the type of shoal configuration, sediment and water conditions have slightly different characteristics during the loading operation. Thus, they require varying times to reach the economic load.

Plume Definition. Additional special dredging studies were conducted in 1974 - early 1975 in Mare Island Straits (September - October), at Richmond Harbor (November) and at Alameda Naval Air Station (December - January). The objective of these studies was to quantify the dredging plume in terms of suspended solids and percent transmission. The procedures previously used during the routine monitoring were modified. A pumping system for water sample collections was added and positioning of the survey vessel was changed.

The pumping system consisted of a Jabsco, self-priming, centrifugal water pump, Model No. 11810-0003 which pumps 1.26 liters per second, and fifteen meters of Mayton vinyl tubing, nineteen millimeters inside diameter. The pump was positioned on the deck of the GRIZZLY, permitting continuous sampling of the water mass. The end of the hose was connected to the protective cage of the InterOceans probe. Its juxtaposition to the photocell was such that its position, i.e., depth, was known and comparisons with percent transmission were possible. Tests indicated that there was an approximate four second lag in the transfer of water from the cage to the spigot on deck.

Floating stations were established in such a way that the horizontal area influenced by the dredge was defined. Monitoring was initiated from three starting points. The first point was directly astern of the dredge, continuing down-current along the centerline of the dredge cut. The second was 50 meters to the starboard or port side of the dredge, continuing downcurrent parallel to the centerline. The third was 100 meters to the side of the dredge parallel to the centerline. Monitoring was at a fixed depth for each monitoring cycle. Measurements were made of conductivity, salinity, temperature, dissolved oxygen, turbidity and current.

Water samples for the analysis of suspended solids were obtained concurrently with the turbidity readings (% transmission). Water samples were obtained as close to the dredge as possible within safe limits. Initial depths during a pre-survey were at the surface, 1, 2.5, 5, 7.5 and 10 meters. From the pre-survey for the monitoring, the selected depths without overflow were 5, 7.5 and 10 meters and with overflow 1, 2.5 and 7.5 meters. These depths were selected to place the emphasis on areas where the greatest impact was expected to occur.

Since hopper dredging is a continuously moving operation, the fixed station positioning proved inadequate. The floating station record with a fixed depth was found efficient and a more effective technique for defining the plume. The hopper dredge operates with a constant speed over the bottom of two knots. This knowledge in conjunction with the data from the current meter enabled development of plume definition.

In addition to hopper dredge monitoring, a clamshell dredge (18 cubic yard bucket) was monitored during operations at the Alameda Naval Air Station. Using currents for determination of centerline, the same pattern of centerline, 50 and 100 meters were sampled. The controlling channel depth at the Air Station is 9.75 meters and measurements of salinity, turbidity, suspended solids and currents were made at 1, 2.5, 5 and 7.5 meters.

The results of the monitoring were plotted to produce a pictorial representation of the plume. The raw plots of the percent transmission data for each project area are attached in Inclosure 5. These plots were interpreted and the extent of the plume defined graphically. The resulting plots showing the "area of influence" are attached in Inclosure 6. The "area of influence" does not necessarily represent a zero reading of the probe but is indicative of a significant increase over ambient. Suspended solid concentrations found via pumped water sample collection in the "area of influence" are presented in Inclosure 7. These results, corrected for current skewness and rounded, have been summarized in Table 6 which presents representative results for each project area. The effect of salinity on flocculation is indirectly apparent when concentrations of plumes are compared between areas. The concentrations are higher in Mare Island Strait, where salinity is lower than it is in the Central Bay projects. Figure 9 depicts the plume configuration in Mare Island. This figure represents an estimated maximum "area of influence" for dredge projects in the Bay. In general, the plume extends from the dredge both in the upper water column, due to overflow, and the lower water column. As distance increases from the dredge the upper plume merges with the lower plume to attenuate light transmission; and increase solids concentrations throughout the water column. Solids concentrations in the upper and mid water column rarely exceed several hundred milligrams per liter except directly adjacent to the hopper dredge overflow ports. Concentrations in the bottom waters are a gram or more. At approximately 300 to 400 meters downstream of the hopper dredge a clear zone appears in the mid to lower water column probably due to the variable pitch, twin screws of the vessel. The plume can extend more than 700 meters downstream. Typically as distance from the dredge increases the plume's distribution becomes increasingly more limited to the bottom waters. However, as evident from the results in Richmond Harbor, surface discoloration can also extend nearly this far downstream. The suspended solids concentrations definitely decrease with distance from the dredge whether hopper or clamshell. Samples were

TABLE 6

TYPICAL SEDIMENT DISTURBANCE IN WATER COLUMN DURING DREDGING

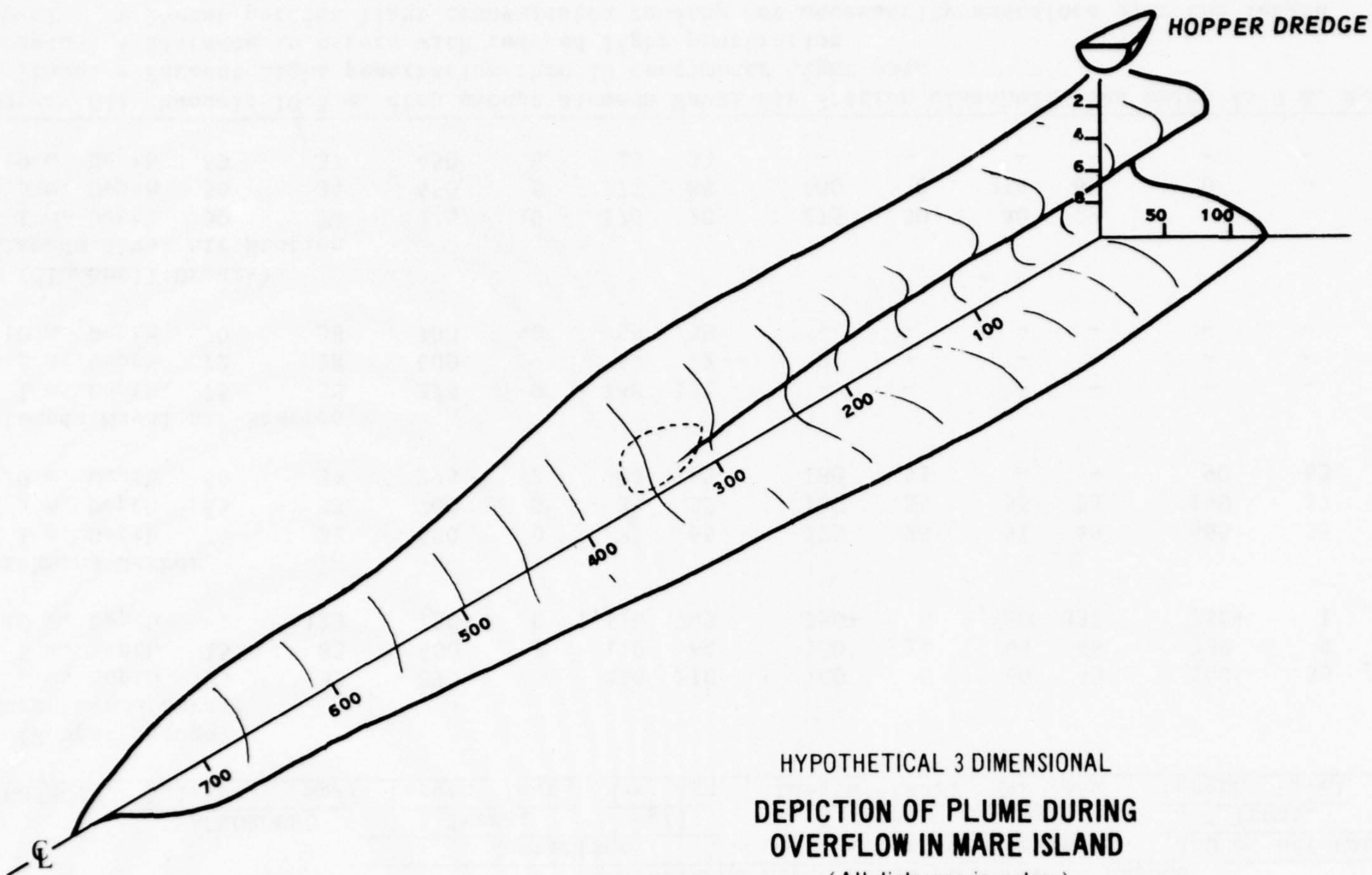
PROJECT	BACKGROUND		DISTURBANCE ALONG LINES PARALLEL TO DREDGE											
			Centerline				50 m. off Centerline				100 m. off Centerline			
			% Trans.		mg/1		% Trans.		mg/1		% Trans.		mg/1	
	% Trans.	mg/1	Length	Level	Max	Ave	Length	Level	Max	Ave	Length	Level	Max	Ave
(Hopper Dredge)														
Mare Island Strait														
1 m. Depth	25	33	275	0	210	210	140	0	60	43	140	35	12	12
5 m. Depth	15	83	600	2	110	64	180	14	46	46	230	9	49	49
10 m. Depth	1	123	750+	0	1,110	743	750+	0	2,600	337	750+	1	260	233
Richmond Harbor														
1 m. Depth	75	31	680	0	82	65	275	25	51	45	685	35	23	23
5 m. Depth	65	33	700	0	39	33	180	55	55	55	140	57	20	20
10 m. Depth	60	39	275	2	200	145	180	55	-	-	90	63	32	32
Alameda Naval Air Station														
1 m. Depth	75	35	275	0	188	131	-	-	-	-	-	-	-	-
5 m. Depth	72	28	600	-	47	42	0	-	-	-	-	-	-	-
10 m. Depth	70	38	700	40	58	58	-	-	-	-	-	-	-	-
(Clamshell Dredge)														
Alameda Naval Air Station														
1 m. Depth	50	24	275	10	170	70	275	30	40	29	-	-	-	-
5 m. Depth	56	34	450	5	172	88	400	0	214	68	0	-	33	29
10 m. Depth	69	37	450	8	118	33	-	-	-	-	-	-	-	-

Note: All channels 10.5 m. deep except Alameda Naval Air Station clamshell area which is 9 m. deep.

% Trans. = Percent light penetration thru 10 centimeter light path

Length = distance in meters with reduced light penetration

Level = lowest percent light transmission reading not necessarily sustained over the length



HYPOTHETICAL 3 DIMENSIONAL

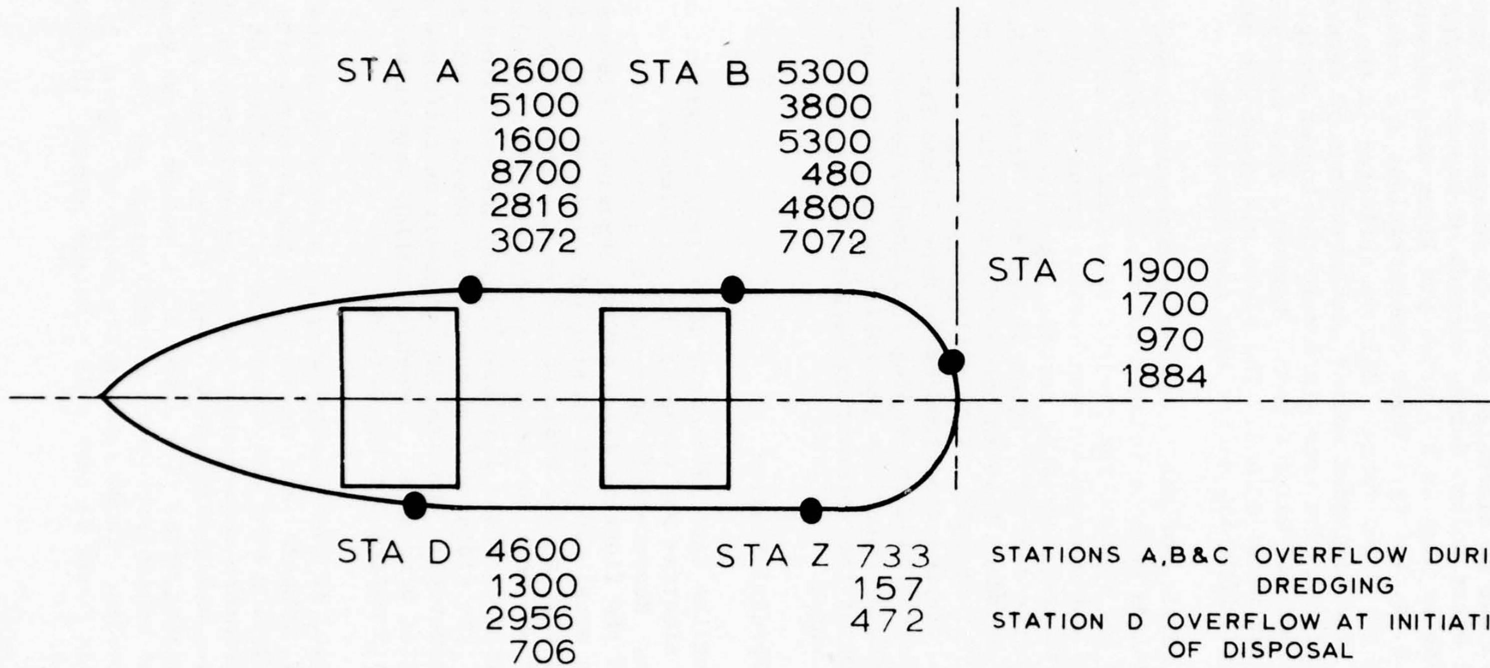
DEPICTION OF PLUME DURING OVERFLOW IN MARE ISLAND

(All distances in meters)

FIGURE 9

SUSPENDED SOLIDS ADJACENT TO HOPPER DREDGE

MILLIGRAMS/LITER



STATIONS A,B&C OVERFLOW DURING DREDGING

STATION D OVERFLOW AT INITIATION OF DISPOSAL

SAMPLES TAKEN DURING MAINTENANCE DREDGING AT MARE ISLAND STRAIT AND RICHMOND HARBOR BY HOPPER DREDGE "HARDING" Sep-Nov 75

STATION Z BOILS AT DISPOSAL DUE TO VESSEL

FIGURE 10

taken adjacent to discharge ports to determine the maximum loading in the upper water column during periods of hopper dredge overflow. Concentrations as high as 8.7 grams per liter were measured (see Figure 10, Stations A, B, and C). These concentrations are reduced quickly to the milligram per liter range. This is reflected in the data presented in Table 6. The suspended solids concentrations 50 meters downstream from the clamshell dredge were similar to the hopper dredge concentrations in the upper and mid water column. However, they were several times lower in the lower water column. The plume was about 300 meters long on the surface and about 450 meters long near the bottom.

The results of the transmission measurements and suspended solids concentrations were correlated to enable curve generation. Curves were developed for each of the project areas and are shown in Figure 11. Pronounced differences between various areas are very apparent. The figure indicates a greater percent light transmission for a given solids loading in the central portion of the Bay (Richmond Harbor and Alameda Naval Air Station) than in the northern portion of the Bay (Mare Island Strait). For example, fifty milligrams of sediment per liter may have a 20 percent transmission reading in Mare Island Strait as compared to a 50 percent transmission reading in Richmond Harbor. Transmission must be augmented by water samples collected in situ to provide a reliable description of the interaction between resuspended or introduced sediments and water.

Disposal Special Studies

During the late 1974-early 1975 dredging period, surveys were performed at Alcatraz and Carquinez Strait Disposal Sites to assess plume dispersion. Measurements were made in a water column cross-section similar to the floating lines during dredging. Since significant (0.5g/l or more) sediment loading was observed only near the bottom, the monitoring program was modified and measurements only were taken at a fixed station, near the bottom, downcurrent of the release. As the dredge turned across a line paralleling current direction, release occurred. The distance from the survey vessel to the dredge varied from 100 to 200 meters. The same measurements as performed during the dredging operation were made. Suspended solids samples were collected at 0.5 and 1 to 1.5 meters off the bottom.

Attempts at the Alcatraz site were hindered because of current velocities, patterns and the depth of the disposal site and plume characterization near the bottom was not possible. At the Carquinez site measurements showed that percent transmission in the upper and mid water column was approximately equal to the levels found at Alcatraz and in the dredging area. The lower water column (less than a meter off the bottom) had concentrations of several grams per liter lasting as long as fifteen minutes. These results are shown in Figure 12. Released mamaterial was found to result in a bottom plume. This directed further

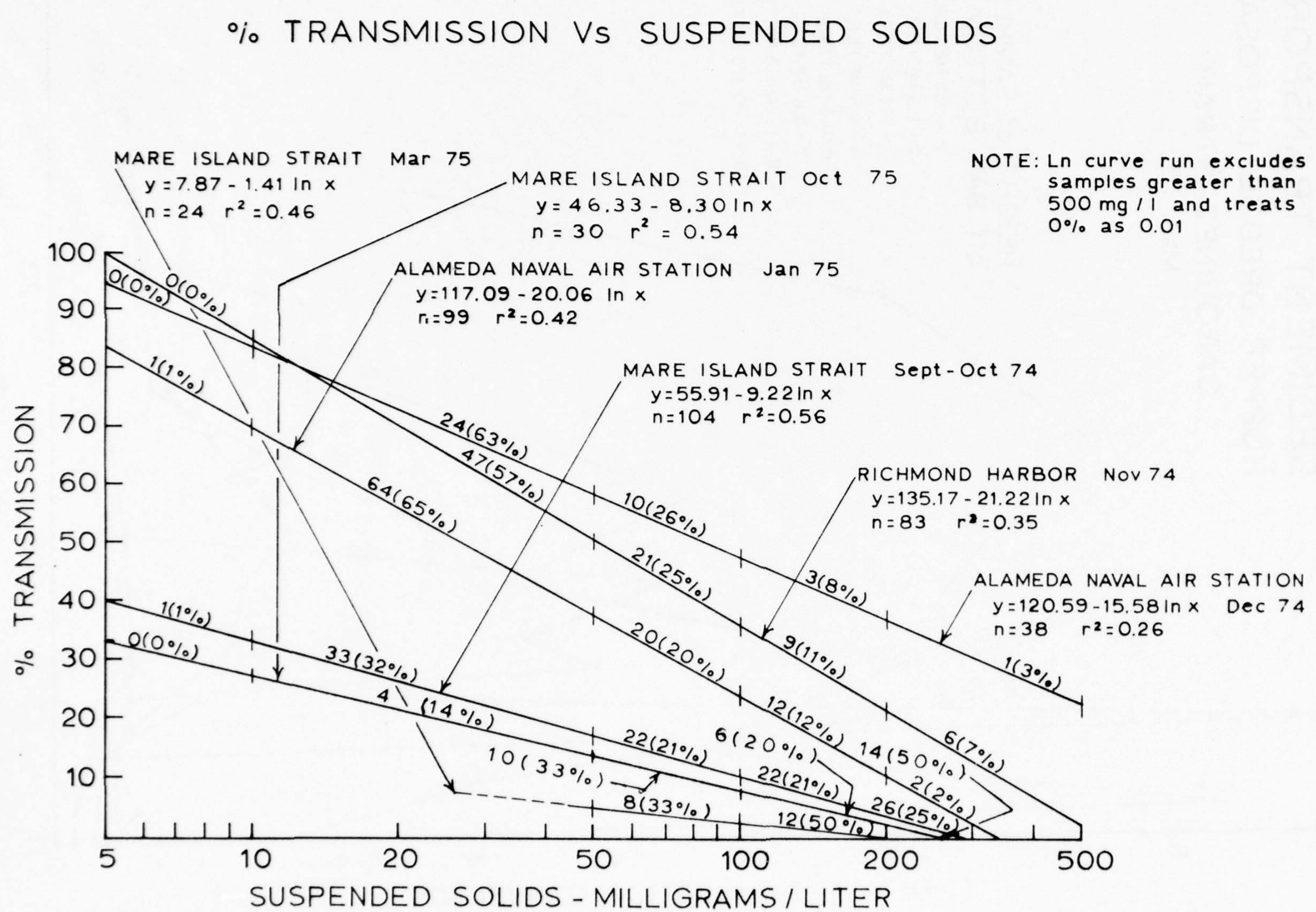

% TRANSMISSION Vs SUSPENDED SOLIDS
MARE ISLAND STRAIT Mar 75
y = 7.87 - 1.41 ln x
n = 24 r² = 0.46
MARE ISLAND STRAIT Oct 75
y = 46.33 - 8.30 ln x
n = 30 r² = 0.54
ALAMEDA NAVAL AIR STATION Jan 75
y = 117.09 - 20.06 ln x
n = 99 r² = 0.42
MARE ISLAND STRAIT Sept-Oct 74
y = 55.91 - 9.22 ln x
n = 104 r² = 0.56
RICHMOND HARBOR Nov 74
y = 135.17 - 21.22 ln x
n = 83 r² = 0.35
ALAMEDA NAVAL AIR STATION Dec 74
y = 120.59 - 15.58 ln x
n = 38 r² = 0.26
NOTE: Ln curve run excludes samples greater than 500 mg / l and treats 0% as 0.01
% TRANSMISSION
SUSPENDED SOLIDS - MILLIGRAMS / LITER
100
90
80
70
60
50
40
30
20
10
5
10
20
50
100
200
500
0(0%)
0(0%)
1(1%)
24(63%)
47(57%)
64(65%)
10(26%)
21(25%)
3(8%)
20(20%)
9(11%)
1(3%)
1(1%)
0(0%)
33(32%)
4
(14%)
22(21%)
10(33%)
8(33%)
6(20%)
22(21%)
12(12%)
14(50%)
6(7%)
2(2%)
26(25%)
12(50%)

FIGURE 11

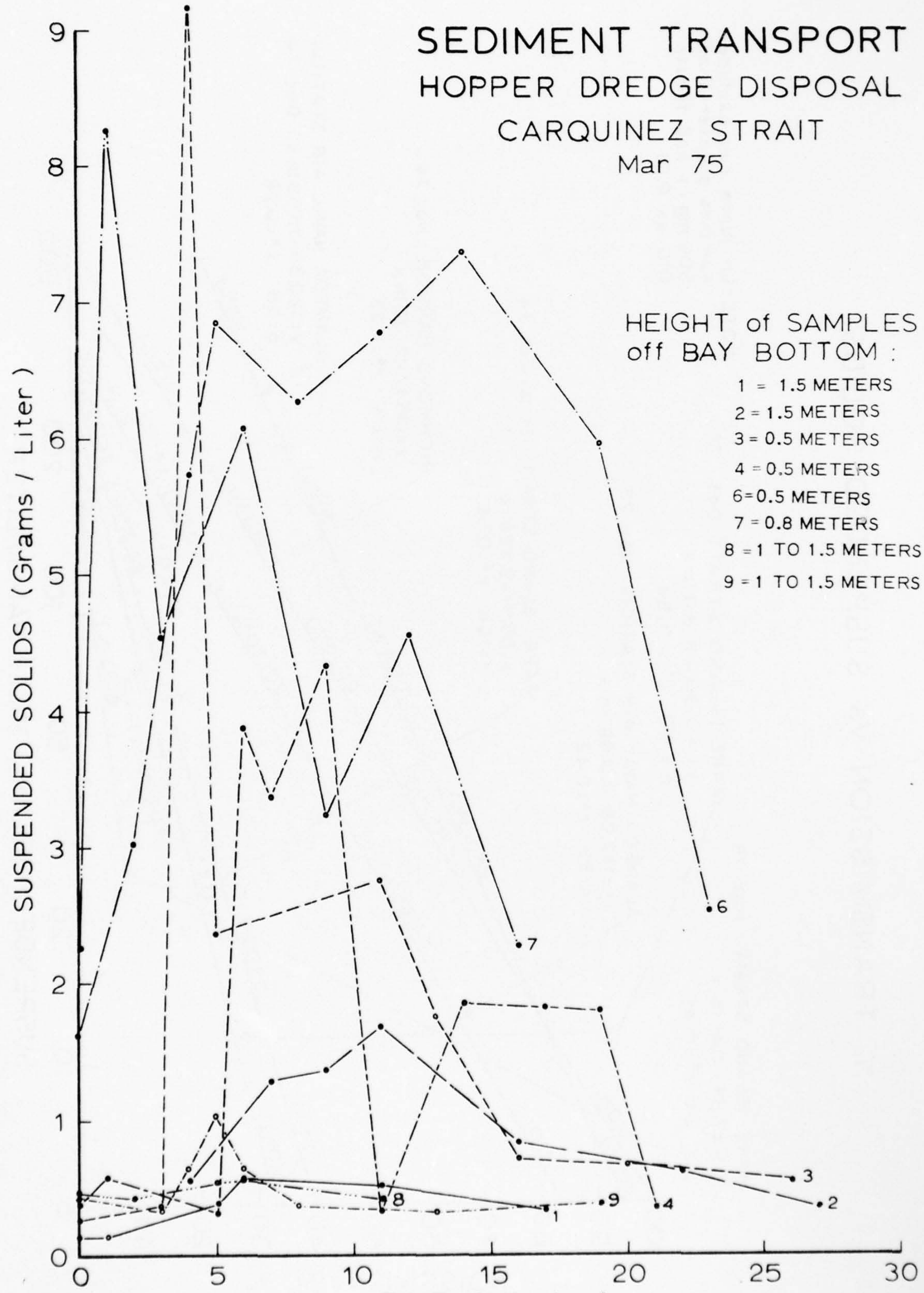
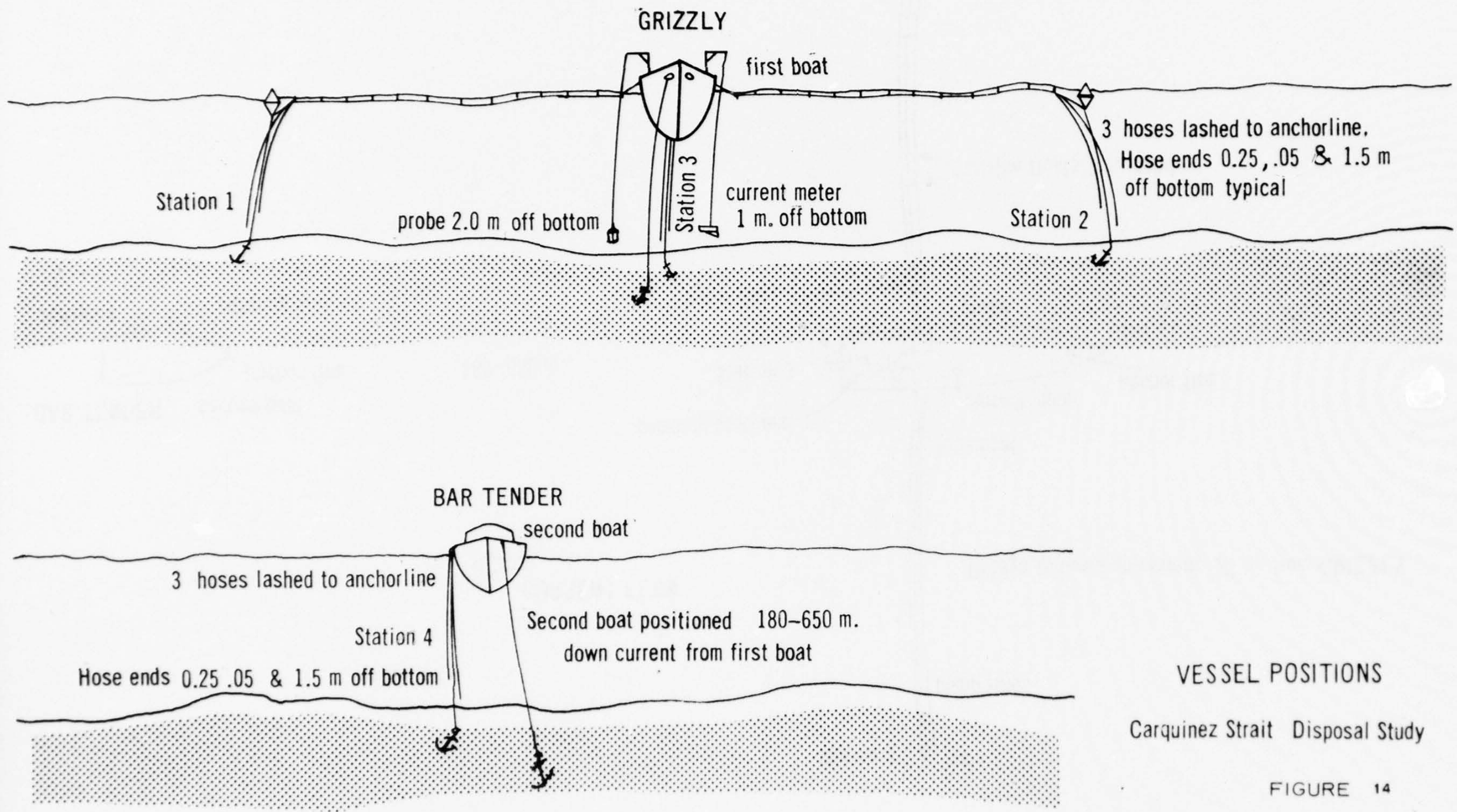

SEDIMENT TRANSPORT
HOPPER DREDGE DISPOSAL
CARQUINEZ STRAIT
Mar 75
HEIGHT of SAMPLES
off BAY BOTTOM :
1 = 1.5 METERS
2 = 1.5 METERS
3 = 0.5 METERS
4 = 0.5 METERS
6 = 0.5 METERS
7 = 0.8 METERS
8 = 1 TO 1.5 METERS
9 = 1 TO 1.5 METERS
SUSPENDED SOLIDS (Grams / Liter)
TIME (Minutes)
0
1
2
3
4
5
6
7
8
9
10
15
20
25
30

FIGURE 12

quantification of the initial dispersion in that zone. A very small percentage of the released material remained in the upper water column to form a surface plume. The dimensions and configuration of a typical surface plume are shown in Figure 13. Suspended solids concentrations on the surface are shown at Stations D and Z in Figure 10. These values are not random samples, but were obtained from observed areas of highest discoloration. The surface plume represents overflow immediately prior to release and the surfacing of boils due to the vessel passing over the release.

Initial Dispersion. In October - November, 1975, monitoring was conducted to determine the horizontal and vertical pattern during initial sediment impact and transport from the Carquinez Strait disposal site. Suspended solids were collected at three depths from the bottom (0.25, 0.5 and 1.5 m.) at four stations simultaneously. The position of the four stations is shown in Figures 14 and 15. The survey vessel GRIZZLY was aligned with the dredge HARDING's position and some 90 meters downcurrent of the release. The BAR TENDER was aligned with the GRIZZLY downcurrent at distances varying from 180 to 650 meters. Measures of percent transmission were taken approximately 2 meters off the bottom. Current measurements were taken at one to two meters off the bottom. The suspended solids samples were obtained using twelve (three at each station) PAR Heavy Duty Diaphram Bilge Pumps, model no. 36600-0000, 12 volt DC. The pumps were rated at 0.50 liters per second. The water was pumped through Mayton vinyl tubing with a nineteen-millimeter inside diameter.

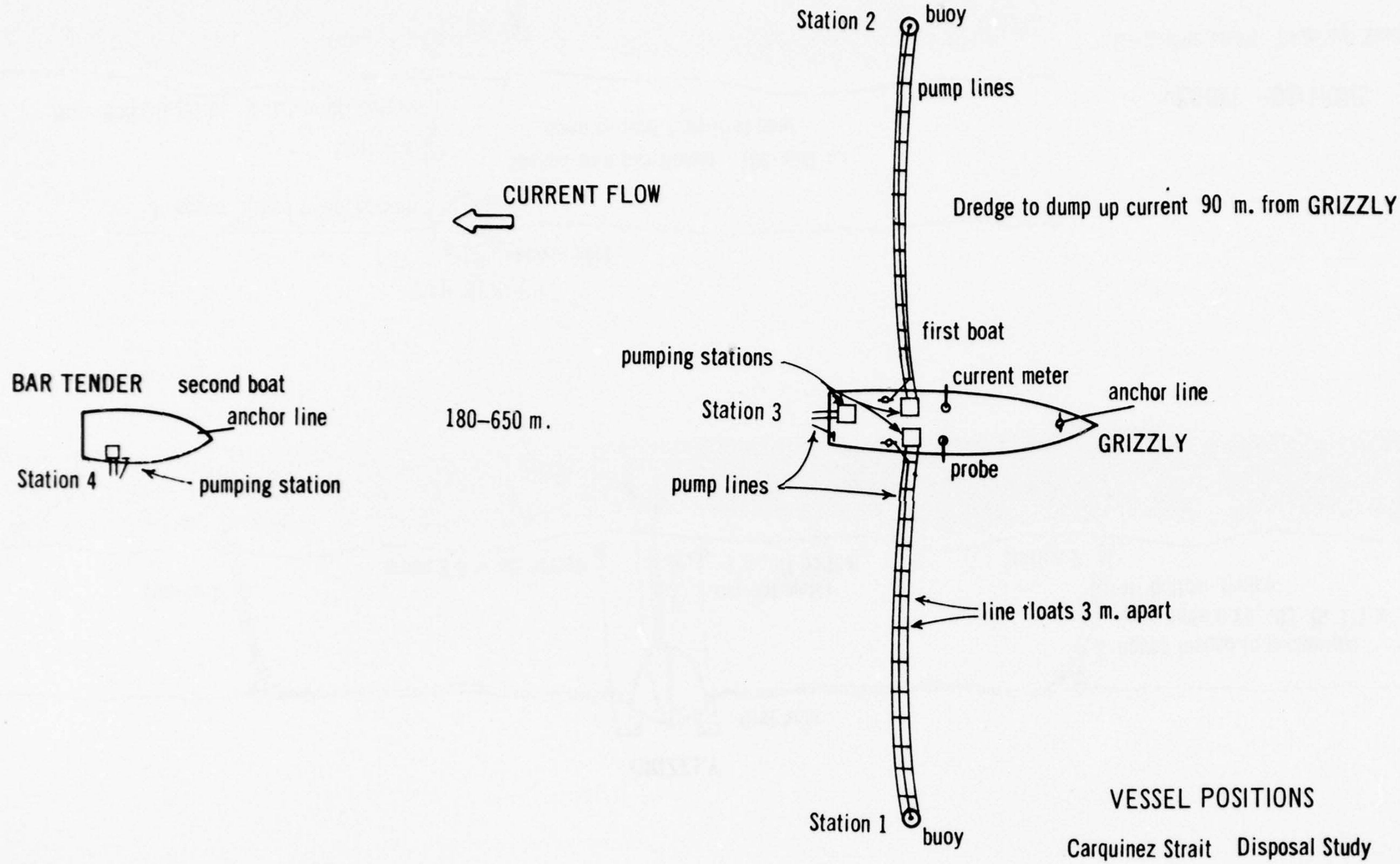
The results of the disposal study at Carquinez Straits are graphically displayed in Figures 16 to 21 and reflect several important findings. First, the solids concentration can be two orders of magnitude higher (20g/l) near the bottom than in the remaining water column (0.2g/l). Second, the plume did not always pass a discrete point (station) as a homogeneous mass. Instead, in many cases, two pulses in different stages of coincidence were observed. Additionally, the plume did not have an uniform concentration gradient with time. The concentration of suspended solids generally seemed to build rapidly followed by a much slower decrease. Third, the highest solids concentrations were consistently found at Station 2 which was positioned on the lower slope of the disposal site. Fourth, cloud velocity seemed to be independent of current velocity. These findings are summarized in Table 7.



VESSEL POSITIONS

Carquinez Strait Disposal Study

FIGURE 14



VESSEL POSITIONS

Carquinez Strait Disposal Study

FIGURE 15

SEDIMENT TRANSPORT – CARQUINEZ STRAIT DISPOSAL
RELEASE 1

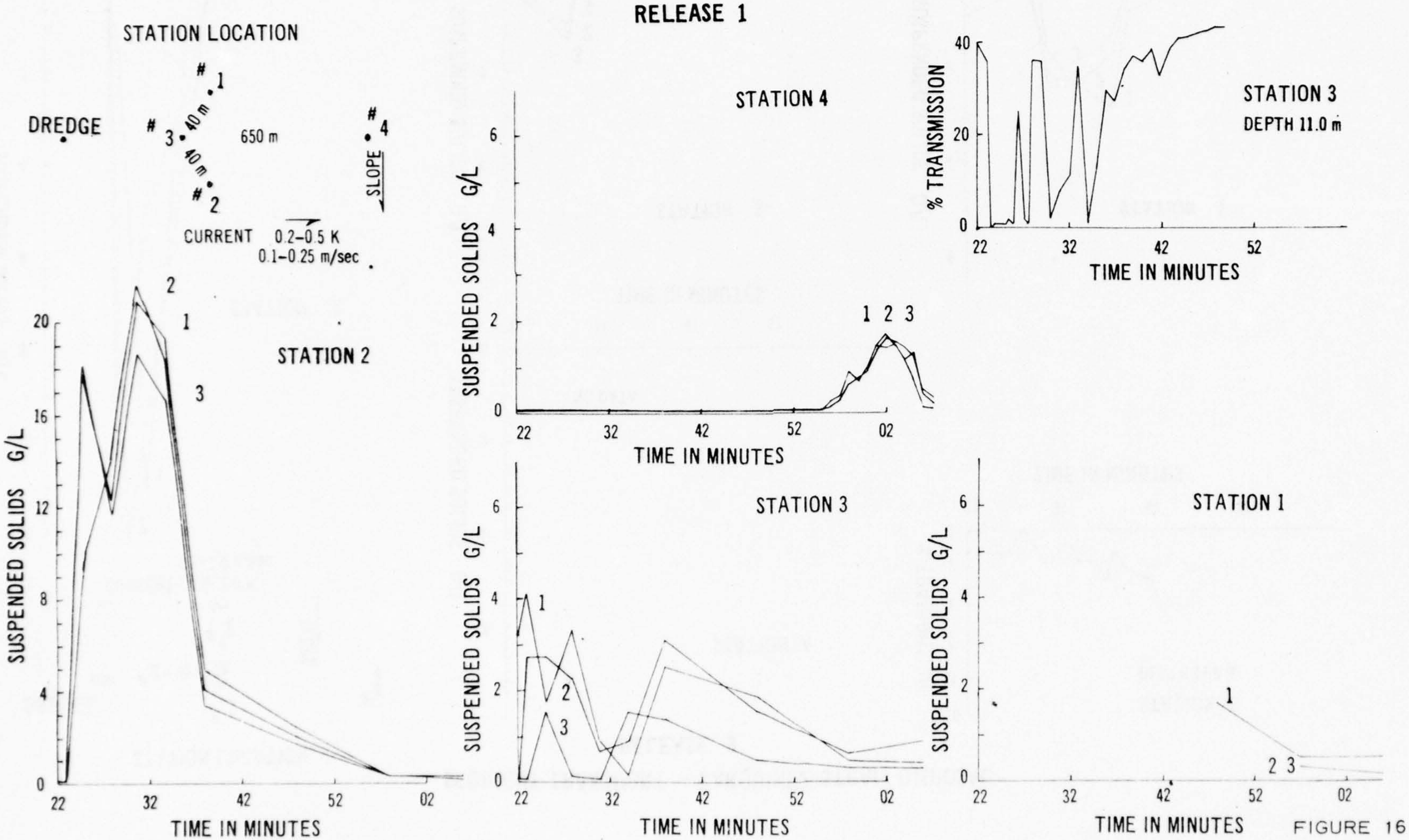


FIGURE 16

SEDIMENT TRANSPORT – CARQUINEZ STRAIT DISPOSAL
RELEASE 3

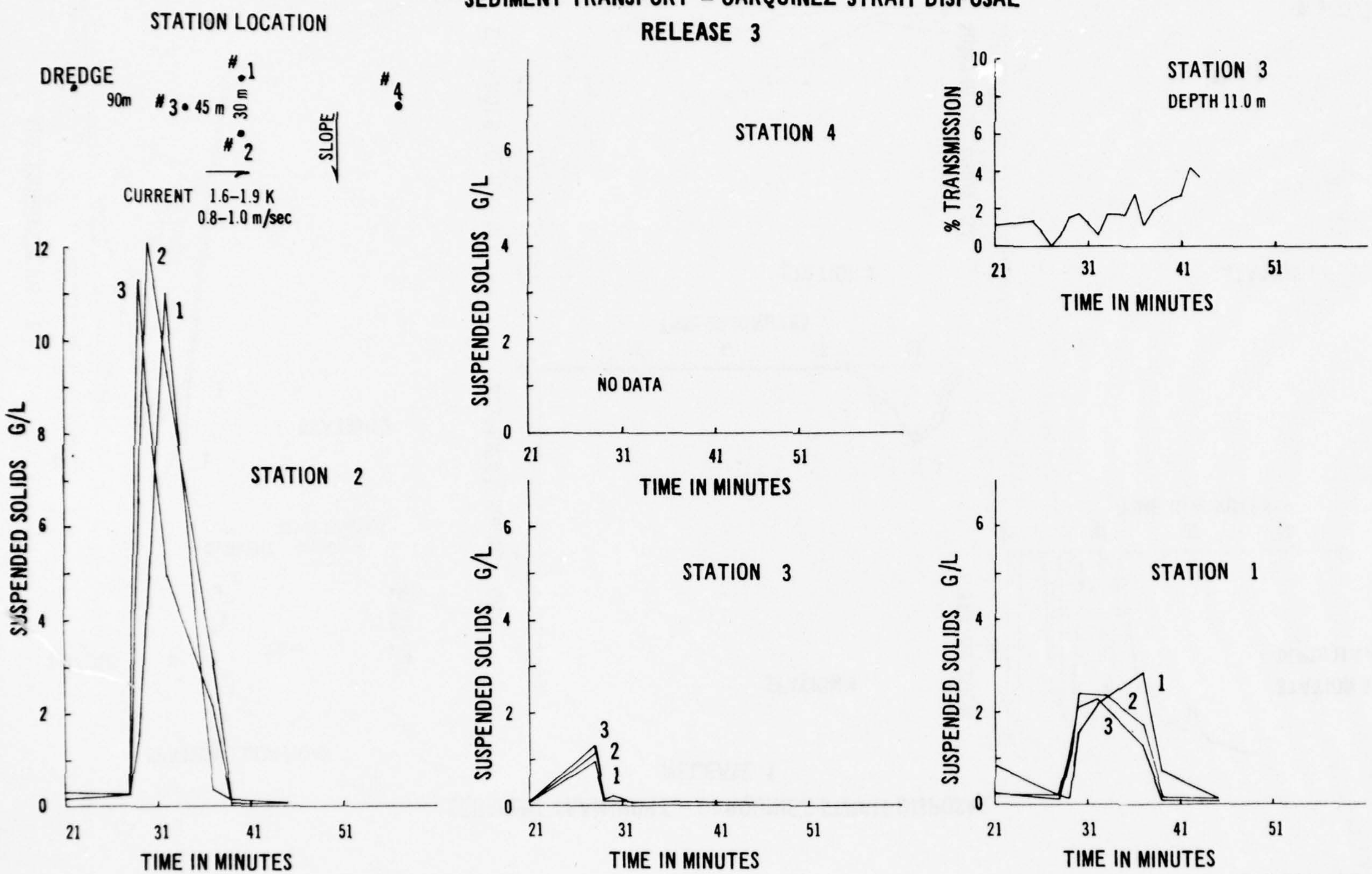


FIGURE 17

SEDIMENT TRANSPORT – CARQUINEZ STRAIT DISPOSAL
RELEASE 4

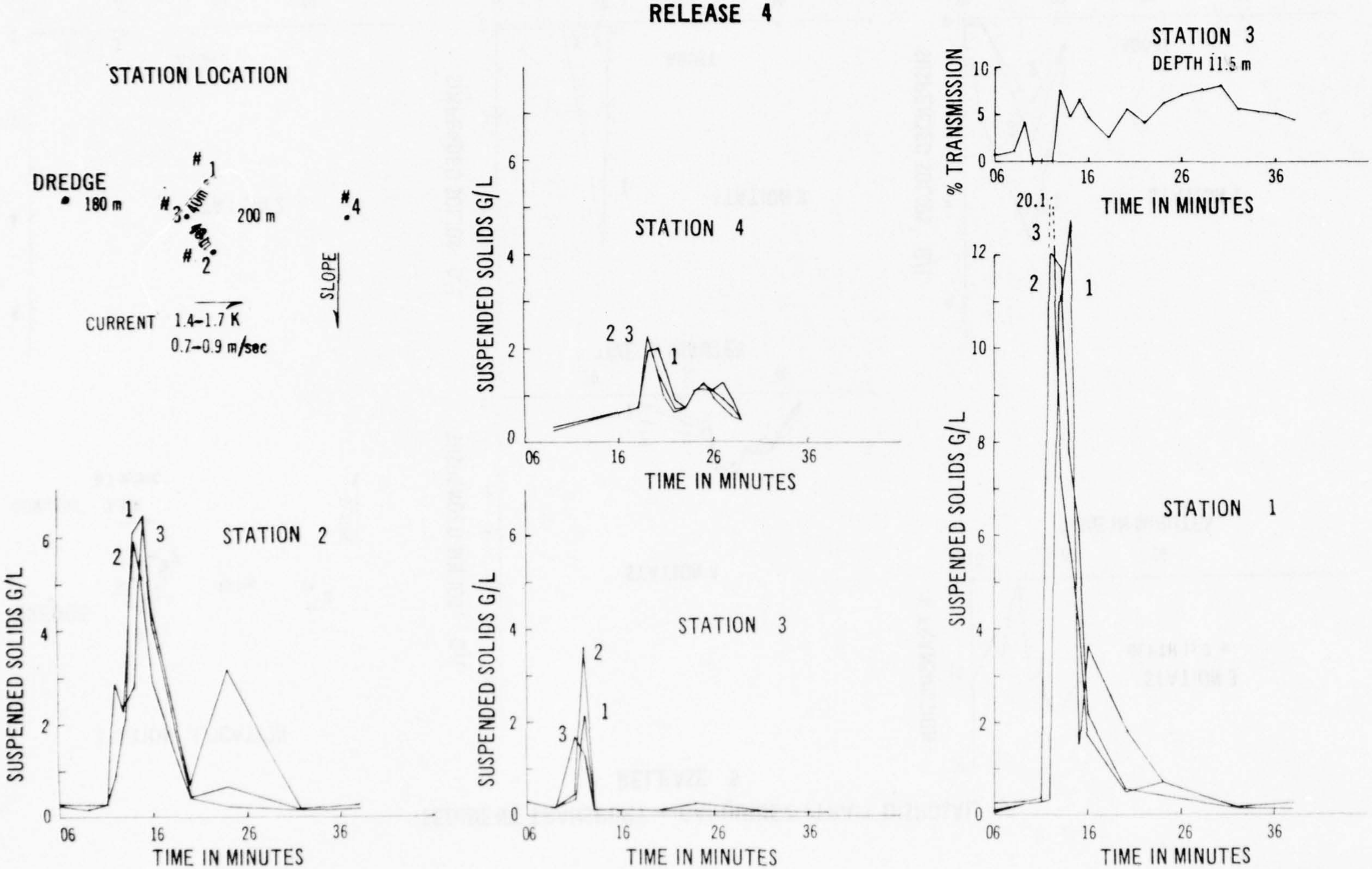


FIGURE 18

SEDIMENT TRANSPORT – CARQUINEZ STRAIT DISPOSAL
RELEASE 5

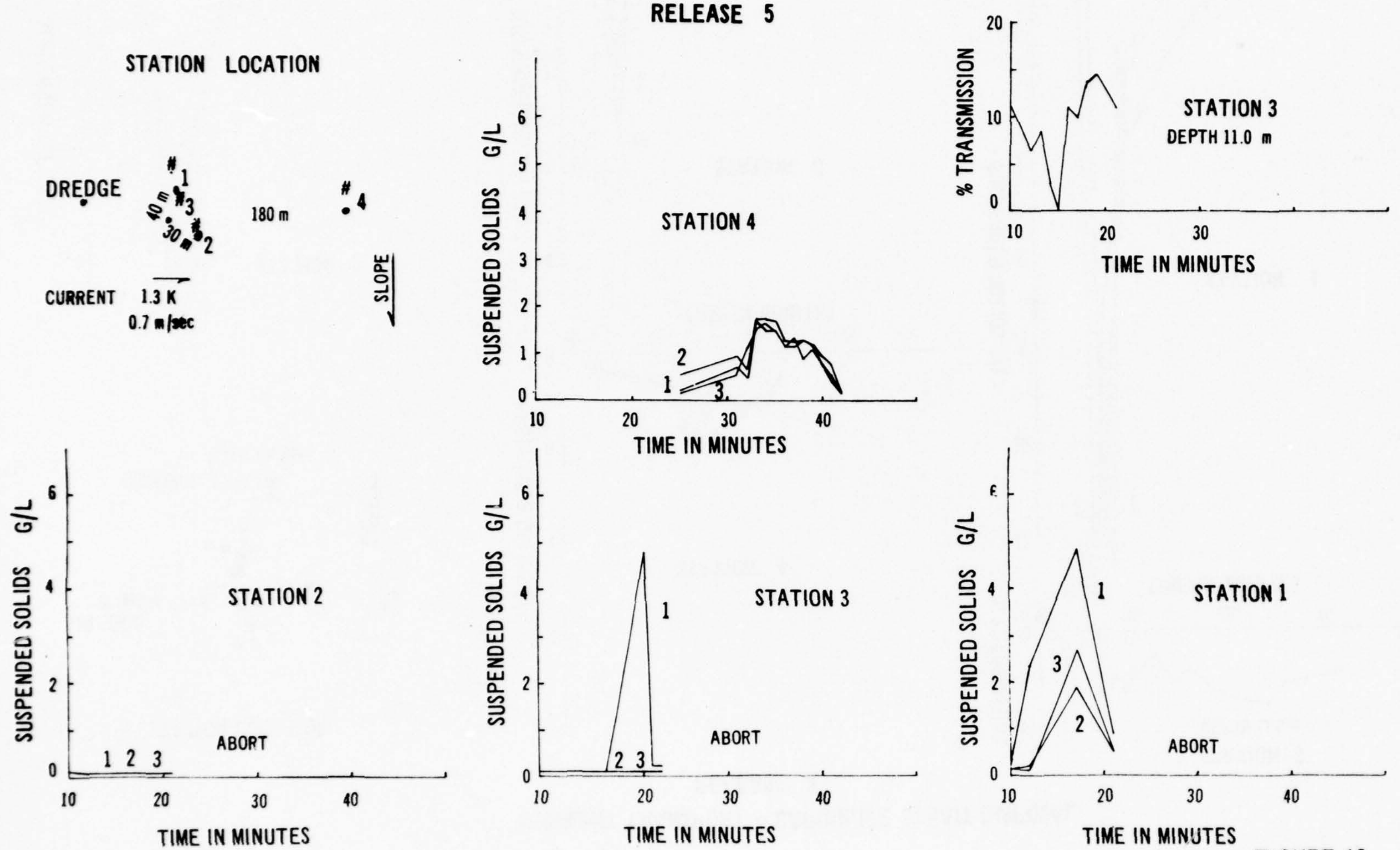


FIGURE 19

SEDIMENT TRANSPORT – CARQUINEZ STRAIT DISPOSAL
RELEASE 6

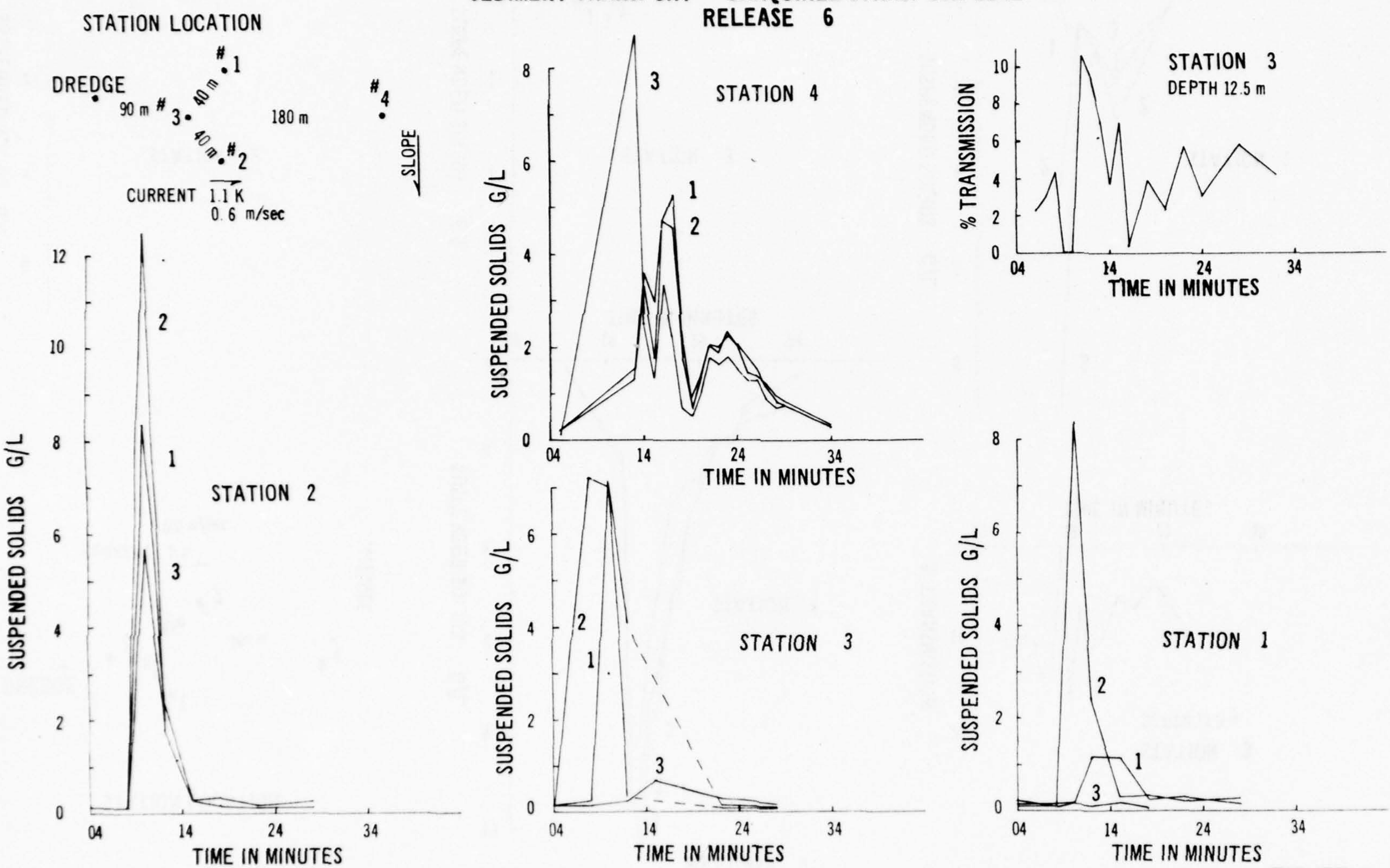


FIGURE 20.

SEDIMENT TRANSPORT - CARQUINEZ STRAIT DISPOSAL
RELEASE 7

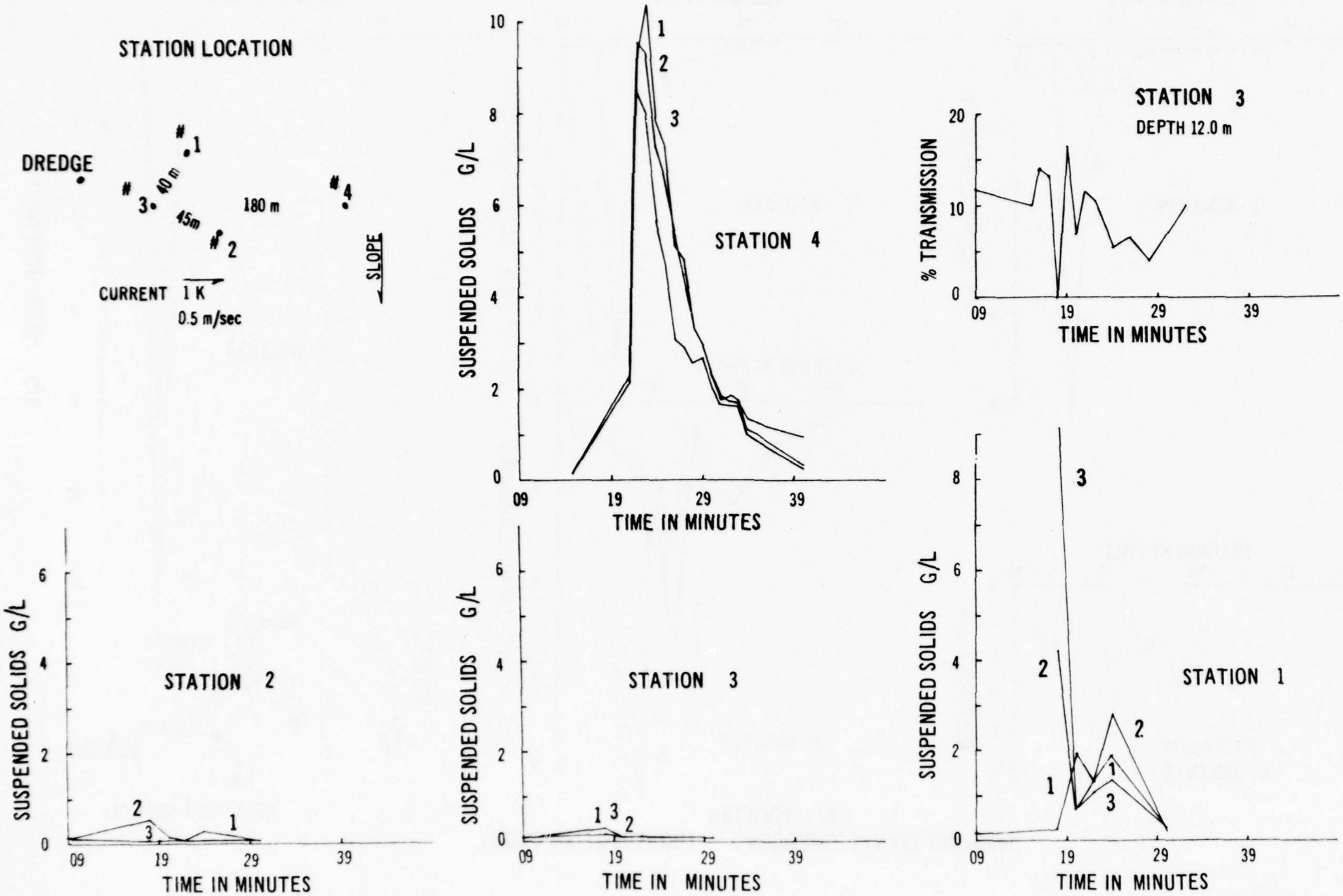


FIGURE 21

TABLE 7

SUMMARY OF INITIAL DISPERSION DATA

Depth (m)	Max. Concentration by Station (g/1) 1	2	3	4	Duration of Cloud (min) 1	2	3	4	Double Pulse lag time (min)	Dist. Bet Sta. 3 and 4 (m)	Current Velocity (m/sec)	Cloud Velocity (m/sec)
0.25	2	21	4	1.8	36	35	-	12	-	650	0.25	-
0.5	-	22	3	1.8					6	650	0.25	0.35
1.5	-	18.5	1.5	1.8					9	650	0.25	0.45
0.25	3	11	0.9	-	10	11	8	-	-	-	-	-
0.5	2.5	12	1.0	-					-	-	-	-
1.5	2.5	11	1.1	-					-	-	-	-
0.25	13	6.5	2	2	27	22	4	11	-	200	.7	0.42
0.5	12	6	3.7	2					9	200	.7	0.42
1.5	20.1	6	1.8	2					-	200	.7	0.56
									6			
0.25	5	5	-	2	10	-	-	18	-	180	.7	0.12
0.5	2	-	-	2					-	180	.7	-
1.5	3	-	-	2					-	180	.7	0.56
0.25	1.2	7	8.5	5	8	7	22	30	-	180	.6	0.43
0.5	8.4	7	12.5	4.5					-	180	.6	0.43
1.5	1	1	5.5	8.8					4	180	.6	0.38
0.25	2	.1	.1	10.5	11	20	-	24	5	180	.5	0.75
0.5	4.2	.5	.2	9.5					-	180	.5	.6
1.5	9	.5	.2	8.5					-	180	.5	.6

Dissolved Oxygen. The routine monitoring program indicated that disposal operations could significantly influence the dissolved oxygen concentration. To obtain more information special studies were conducted at the Carquinez Strait and San Pablo Bay disposal sites. The Alcatraz disposal site was not studied because of the inability to collect accurate data near the bottom.

The field studies at Carquinez Strait were conducted during January 1973 in conjunction with the Mare Island Strait dredging operation. Dredging and disposal were performed by two trailing suction hopper dredges (17 January, dredge BIDDLE and 29 January, dredge HARDING). Two research vessels were used during each study period (R/V Commanche and Evie-K). The field work was accomplished under Contract No. DACW07-73-C-0051 with the consulting firm of Brown and Caldwell, San Francisco. Their report is attached as Inclosure 8.

During each study period discrete measurements of dissolved oxygen were taken with two Martek Mark II multiple-probe units with analog read-out, one aboard each research vessel. The two instruments were raised and lowered through the water column in the disposal area to record dissolved oxygen levels, before, during and after disposal operations. The dissolved oxygen probes were calibrated and readings periodically verified by water sample collection and analysis using Winkler Titration procedures.

During the 17 January study period six releases were monitored. The vessel Evie-K was employed as a drifting station during all six releases. The Evie-K moved in behind the dredge BIDDLE prior to releases, and then drifted with the surface water mass. The vessel Commanche was anchored at a fixed station during all six releases. In all cases the BIDDLE made its release against the current 30 to 60 meters upcurrent of the fixed station. Releasing against the current permitted greater control of the dredge.

During the 29 Janaury study period eight releases were monitored. The Evie-K was employed as a fixed station for seven of the eight releases. The Comanche was again anchored during all releases. The smaller dredge HARDING was able to release against current 15 meters or less upcurrent from the fixed station for all releases.

The data collected was analyzed to determine the number of significant dissolved oxygen reductions. Analysis of significance was assesed at the P=0.05 level. Aberrations outside of two standard deviations were termed significant. Ten of the fourteen releases were found to cause significant depressions. Table 8 summarizes the results of the two study periods.

TABLE 8

DISSOLVED OXYGEN STUDY AT CARQUINEZ STRAIT

Release No.	Vessel	Distance (meters)	Depth (meters)	Variation	Magnitude (mg/L) 1/	Duration (minutes)
(17 January 1973)						
1A	Evie-K	Drifting	0-9	NSC 2/	-	-
2A	"	"	0-9	NSC	-	-
3A	"	"	0-13	NSC	-	-
4A	"	"	0-12	NSC	-	-
5A	"	"	0-9	NSC	-	-
6A	"	"	0-9	NSC	-	-
1A	Comanche	30-60	NDO 3/	NDO	NDO	NDO
2A	"	30-60	NDO	NDO	NDO	NDO
3A	"	30-60	0-11	NSC	-	-
4A	"	30-60	0-11	Decrease	5.1	2
5A	"	30-60	0-11	NSC	-	-
6A	"	30-60	0-10	Decrease	2.9	4
(29 January 1973)						
1B	Evie-K	15 or Less	0-19	Decrease	5.3	1.5
2B	"	15 or Less	15-18	Decrease	3.7	2.0
3B	"	15 or Less	0-18	Decrease	2.8	1.0
4B	"	Drifting	0-15	Decrease	1.6	2.0
5B	"	15 or Less	PMF 4/	PMF	PMF	PMF
6B	"	15 or Less	0-14	Decrease	5.0	1.0
7B	"	15 or Less	0-12	Decrease	5.5	1.0
8B	"	15 or Less	PMF	PMF	PMF	PMF
1B	Comanche	15 or Less	9-14	Decrease	3.8	2.0
2B	"	15 or Less	6-13	Decrease	3.8	3.0
3B	"	15 or Less	12-13	Decrease	4.2	1.0
4B	"	15 or Less	12	Decrease	1.2	1.0
5B	"	15 or Less	12	Decrease	1.0	0.5
6B	"	15 or Less	2-11	Decrease	3.4	1.5
7B	"	15 or Less	6-11	Decrease	3.0	0.5
8B	"	15 or Less	10	Decrease	4.2	1.5

1/ Magnitude defined as variation beyond two standard deviations.
2/ NSC - No significant change at P=0.05.
3/ NDO - No data obtained.
4/ PMF - Probe malfunction - Probe lowered into bottom mud and fouled.

TABLE 8

DISSOLVED OXYGEN STUDY AT CARQUINEZ STRAIT

Release No.	Vessel	Distance (meters)	Depth (meters)	Variation	Magnitude (mg/L) 1/	Duration (minutes)
(17 January 1973)						
1A	Evie-K	Drifting	0-9	NSC 2/	-	-
2A	"	"	0-9	NSC	-	-
3A	"	"	0-13	NSC	-	-
4A	"	"	0-12	NSC	-	-
5A	"	"	0-9	NSC	-	-
6A	"	"	0-9	NSC	-	-
1A	Comanche	30-60	NDO 3/	NDO	NDO	NDO
2A	"	30-60	NDO	NDO	NDO	NDO
3A	"	30-60	0-11	NSC	-	-
4A	"	30-60	0-11	Decrease	5.1	2
5A	"	30-60	0-11	NSC	-	-
6A	"	30-60	0-10	Decrease	2.9	4
(29 January 1973)						
1B	Evie-K	15 or Less	0-19	Decrease	5.3	1.5
2B	"	15 or Less	15-18	Decrease	3.7	2.0
3B	"	15 or Less	0-18	Decrease	2.8	1.0
4B	"	Drifting	0-15	Decrease	1.6	2.0
5B	"	15 or Less	PMF 4/	PMF	PMF	PMF
6B	"	15 or Less	0-14	Decrease	5.0	1.0
7B	"	15 or Less	0-12	Decrease	5.5	1.0
8B	"	15 or Less	PMF	PMF	PMF	PMF
1B	Comanche	15 or Less	9-14	Decrease	3.8	2.0
2B	"	15 or Less	6-13	Decrease	3.8	3.0
3B	"	15 or Less	12-13	Decrease	4.2	1.0
4B	"	15 or Less	12	Decrease	1.2	1.0
5B	"	15 or Less	12	Decrease	1.0	0.5
6B	"	15 or Less	2-11	Decrease	3.4	1.5
7B	"	15 or Less	6-11	Decrease	3.0	0.5
8B	"	15 or Less	10	Decrease	4.2	1.5

1/ Magnitude defined as variation beyond two standard deviations.
2/ NSC - No significant change at P=0.05.
3/ NDO - No data obtained.
4/ PMF - Probe malfunction - Probe lowered into bottom mud and fouled.

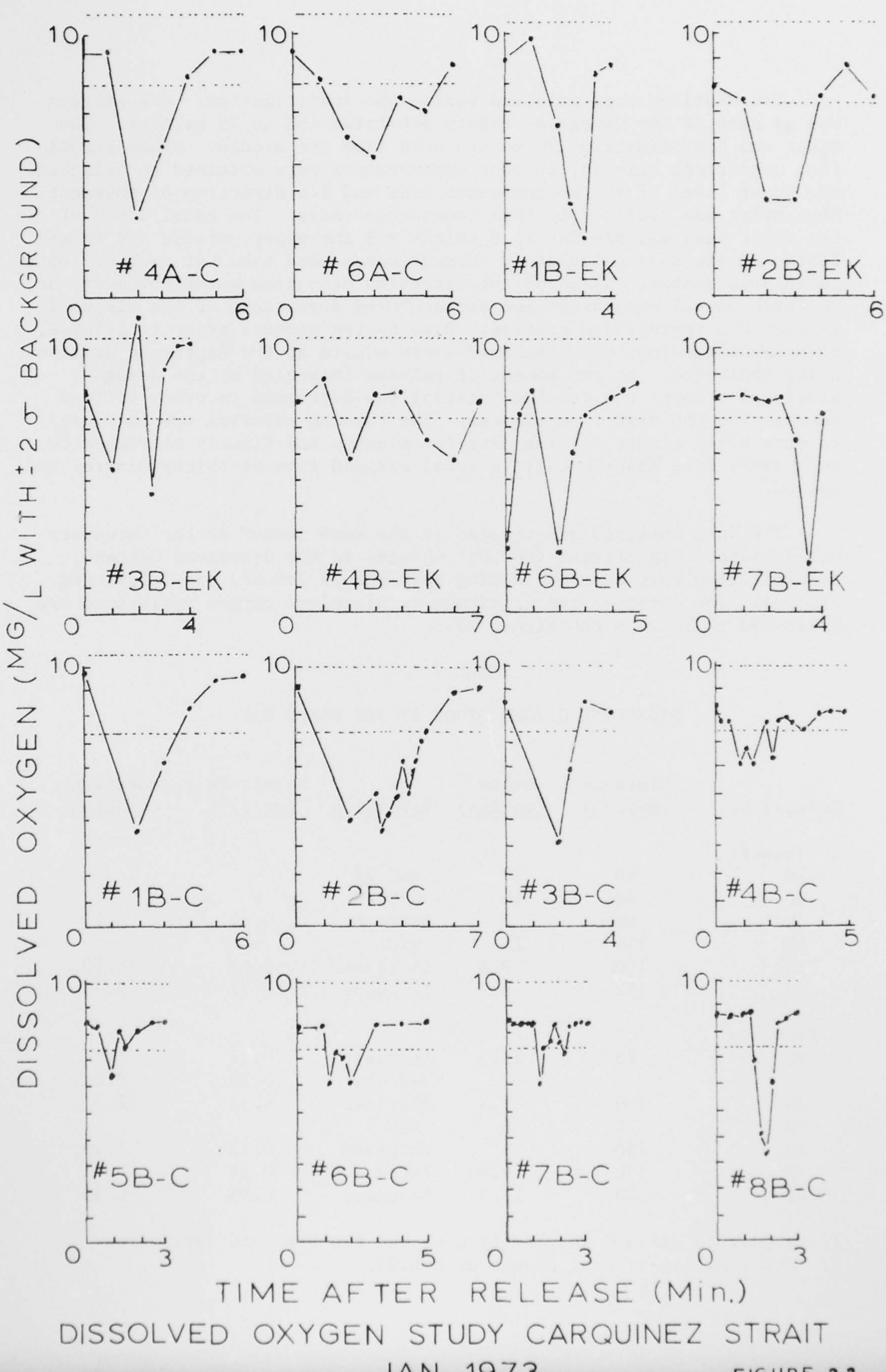
The Evie-K was utilized as a drifting station during seven releases (1-6A and 4B). On only one occasion (4B) was a depression in oxygen observed. The Comanche was utilized as a fix station 30 to 60 meters downcurrent from the dredge BIDDLE during six releases (1-6A) and observed depressions after each of two releases (4A and 6A). The disposal operation was modified during these two releases. Normal operation of the release is to open the twelve doors in pairs in order to maintain vessel stability. The BIDDLE was requested to open all hopper doors simultaneously in order to generate the "worst" condition. The Comanche was employed as a fixed station 15 meters or less from the dredge HARDING during eight releases (1-8B) and the Evie-K during five releases (1-3B, 7 & 8B). In each instance an oxygen reduction was observed. All observed reductions during both study periods occurred in the lower water column.

The magnitude and duration of the sixteen observed dissolved oxygen reductions are displayed graphically in Figure 22. The single reduction observed by a drifting station (4B - Evie-K) lasted two minutes during which oxygen levels fell 1.6 milligrams per liter (mg/l). Depressions observed at the fixed station 30 to 60 meters downcurrent from release (4A & 6A - Comanche) lasted 2 and 4 minutes respectively with magnitudes of 5.1 mg/l and 2.9 mg/l. A measurement taken 15 meters or less downcurrent from release was the greatest recorded reduction during the study (5.5 mg/l). The duration of the depression did not correlate with current velocities.

As a result of the dissolved oxygen reductions recorded during disposal operations at Carquinez Straits in 1973, a complementary field investigation was planned and executed at the San Pablo Bay disposal site in 1974. The knowledge gained during the prior year's investigations was utilized to refine the monitoring procedures.

Two factors were apparent: first, drifting stations were not successful for detection of depressions. Second, depressions occurred only in the lower water column. These factors were incorporated into the study design, as was the decision to fix the probe in the water column such that readings just prior to engulfment by the plume would reflect ambient conditions.

The field studies were conducted on 29 January and 5 February in conjunction with the maintenance operations at Pinole Shoal ship channel. The operations were performed by the hopper dregdge HARDING. During the two-day study the Corps of Engineers survey vessel GRIZZLY was utilized as a fixed station at the disposal site. Dissolved oxygen and turbidity were monitored with the Inter-Oceans water quality probe. The dissolved oxygen probe was calibrated and readings periodically verified by water sample collection and analysis using Winkler Titration procedures. The consulting firm of Environmental Quality Analysts, Inc., a division of Brown and Caldwell, performed a supplementary investigation of the disposal operations on 5 February under Contract No. DACW07-74-C-0044. Their report is presented in Inclosure 9.



DISSOLVED OXYGEN STUDY CARQUINEZ STRAIT

JAN. 1973

FIGURE 22

Two stations were utilized during the investigation. One station was as near to the dredge as safety permitted (60 to 75 meters). The other was approximately 150 meters away from the dredge. Since stratified conditions existed, current measurements were obtained to delineate the upper level of the bottom water mass and its direction of movement. Monitoring was confined to this lower water mass. The total depth of the water mass was divided into thirds and the upper, middle and lower depths of the mass calculated. Measurements were taken at each of these calculated depths. Based on the direction of bottom water movement the research vessel was positioned and anchored downstream of the disposal site at the appropriate station. Five to ten minutes prior to release, background readings were obtained every minute at the depth and station being monitored. At the moment of release (signaled by the dredge blowing its horn) the reading interval was decreased to every fifteen seconds for the next five minutes. The reading interval was increased to once every minute for the next ten minutes and finally increased to once every five minutes until a total elapsed time of thirty minutes had passed.

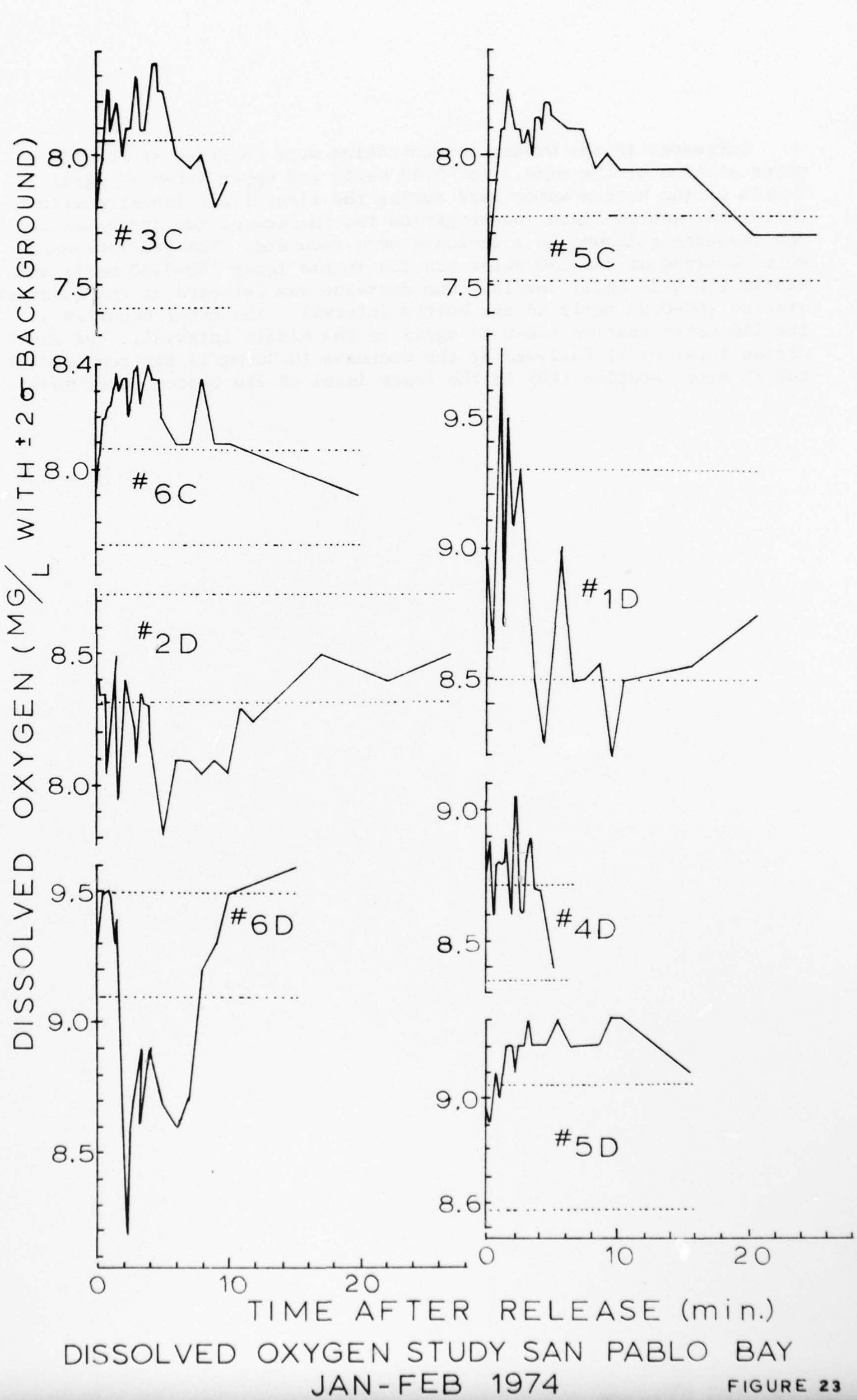
The data obtained was treated in the same manner as the Carquinez Strait data. Significant (P=0.05) changes in the dissolved oxygen concentration were observed during both the 29 January and 5 February studies. The duration and magnitude of dissolved oxygen variations are presented in Table 9 and Figure 23.

TABLE 9

DISSOLVED OXYGEN STUDY AT SAN PABLO BAY

Release No.	Distance (meters)	Depth (meters)	Variation	Magnitude (mg/l) 1/	Duration (minutes)
29 January					
1C	60	12	NSC 2/	-	-
2C	60	10	NSC	-	-
3C	60	8	Increase	0.61	4.25
4C	150	11	NSC	-	-
5C	150	9.5	Increase	0.48	16.75
6C	150	8	Increase	0.77	9.75
5 February					
1D	75	11.5	Increase	0.47	1.5
			Decrease	0.30	9.0
2D	150	9.5	Decrease	0.53	11.5
3D	75	8	NSC		
4D	150	11	Increase	0.23	1.25
5D	150	9.5	Increase	0.24	16.75
6D	60	11.3	Decrease	0.93	6.25

1/ Magnitude defined as variation beyond two standard deviations.
2/ NSC - No significant change at P=0.05.



DISSOLVED OXYGEN STUDY SAN PABLO BAY
JAN-FEB 1974

FIGURE 23

Increases in the oxygen concentration were recorded at the 150 meter station at the middle (5C-0.48 mg/l) and upper (6C-0.77 mg/l) levels of the bottom water mass during the first field investigation. During the second field investigation two increases, two decreases and one increase followed by a decrease were recorded. The two increases were observed at the 150 meter station in the lower (4D-0.23 mg/l) and middle (5D-0.24 mg/l) levels. One decrease was detected at the 60 meter station (6C-0.93 mg/l) in the bottom interval. The other occurred at the 150 meter station (2D-0.53 mg/l) in the middle interval. The increase (0.47 mg/l) followed by the decrease (0.30 mg/l) was recorded at the 75 meter station (1D) in the lower level of the bottom water mass.

DISCUSSION

Dredging and disposal activities inherently cause a disturbance and redistribution of bottom sediments. A major element necessary for evaluating the environmental impact of a dredge or disposal operation is the determination of the interactions between sediment and water during this disturbance and redistribution. The characteristics of this interaction dictate the nature of potential adverse effects which may be chemical and/or physical. Chemical reactions resulting from sediment-water interactions have been intensively studied in the laboratory during the last several years (Chen et al, 1975; Appendix F, Crystalline Matrix). Physical influences on organisms have also been studied in the laboratory (Sherk et al, 1974; Appendix G, Physical Impact). To determine the pertinence of observed organismic impacts it was essential to delineate water quality changes resulting from in-Bay dredging and disposal operations. Knowledge gained from monitoring the nature of sediment-water interactions can now be integrated with the results of the laboratory studies to help predict potential biological impacts.

Sediment-Water Interactions

The nature of sediment-water interactions, as affected by the type and mode of disturbance or resuspension, dictates the changes occurring in water quality conditions. Sediment-water interactions imply both chemical reactions and sediment loading of the water-column. The type, magnitude and duration of chemical reactions caused by operations are contingent on the chemical state of the excavated sediment and the amount of mixing. Chemical state characteristics which must be considered include organic and exotic contaminant loading, salinity, pH, aerobic vs anaerobic, etc. Although a sediment may be "ripe" or have a high activity potential for a particular reaction, that reaction may not occur if the internal equilibrium is not disrupted. For example, a sediment might have a very high oxygen demand but, if the sediment's equilibrium is not disrupted by the addition of oxygen, the reaction can not proceed. Mixing of sediments with water is primarily responsible for upsetting the internal chemical stability of sediments. During the dredging and disposal operation there is an inherent mixing of sediment and water. As the level of agitation increases, the number of discrete particles contacting the water mass and thus the potential for chemical reactions increases.

Sediment loading of the water column is primarily contingent on the physical properties of the sediment, i.e., particle size, cohesion, liquid limit, interstitial salinity, etc. These properties control the behavior of the particulates in the water column. Particle size influences the duration required for settling of the particles. Duration as defined by Stoke's Law, can be modified by flocculation and aggregation of the individual particles. When flocculation occurs slow settling particles (i.e., silts and clays) fall as rapidly a sand particles (Krone, 1962). As cohesive properties are reduced by agitation, i.e. increased void space, the particles begin to act separately instead of as a mass.

The dredging operation causes different sediment-water interactions than the disposal operation. Dredging is a sediment removal process. It introduces small amounts of sediment-laden water over an extended period of time. Disposal on the other hand, introduces a large amount of sediment at near in situ water content during a short time frame. Thus the nature of induced chemical reactions and sediment loading are different for each of the two operations. Any evaluation of sediment-water interactions must be specific to either the dredging or disposal operation.

Interactions During Dredging

Chemical Reactions. The monitoring of selected chemical parameters during dredging operations in San Francisco Bay indicated that only the dissolved oxygen concentration was consistently affected. During stratified conditions, turbulence caused by the operation could introduce high salinity or low temperature water from the bottom into the upper water column. The specific rate of stability re-establishment was dependent on the density differences of strata and on current velocities. Aberrant pH readings were occasionally observed. Such changes resulted from the resuspension of sludges or other deposited chemicals. Changes never exceeded two pH units and were generally in the direction of greater alkalinity. Thus, monitoring showed infrequent dredging-related fluctuations in salinity/conductivity, temperature or pH. Changes in the dissolved oxygen concentration, on the other hand, were observed approximately a quarter of the monitoring periods during dredging operations.

A vertical profile of the sediment column in San Francisco Bay shows an 8-10 cm layer of oxidized olive gray sediment overlying a dark gray anoxic or reduced sediment. Several investigators have shown when reduced sediments are resuspended their oxygen consumption rates increase significantly above quiescent benthal rates (Isaac, 1965; Servizi et al, 1969; Berg, 1970). During the disturbance and resuspension caused by the dredging operation, oxygen consumption is increased. This reduces the ambient oxygen concentration areal of the activity. This reduction can be quite severe in some situations (Brown and Clark, 1968; USACE, 1969). Hopper dredge monitoring indicated that reductions were typically greatest in the upper and lower water column. Changes in the upper water column resulted from introducing sediment-laden waters via overflow. The oxygen level could be reduced as much as 2 mg/l at 50 meters downstream of the overflow. As distance from the source increased the demand or oxygen consumption decreased until, at 100 meters downstream, deviations from ambient were not observed. Reductions in the lower water column were the result of resuspending sediments during the cutting operation. Because the solids concentrations are higher in this zone than in the overflow, and because atmospheric rearation is not

available, oxygen reductions are greater in magnitude and duration. Decreases of 4 mg/l were observed in the bottom water at 50 meters downstream. By 400 meters the oxygen concentration had returned to background levels.

Three factors are primarily responsible for determining the direction and intensity of dissolved oxygen fluctuations. The chemical composition of the material influences the intensity of its oxygen demand. The greater its content of oxygen consuming chemicals and organic matter and the lower its oxidation-reduction potential, the more likely it is to negatively influence the dissolved oxygen concentration, i.e., the rate of available oxygen utilization is dependent on the chemical composition. Second, as particulate contact (surface area) with the water column increases, the demand intensifies. Third, the amount of mechanical perturbation influences the chemical characteristics of the slurry, e.g., introducing air bubbles, and, in this way, modifies its demand and the direction of fluctuations.

The duration of a dissolved oxygen reduction is controlled by a combination of factors operating simultaneously. While the material is in suspension, the demand of the material is being met by available oxygen. This demand can be satisfied and ambient levels can return; or, the material can settle (reducing the contact time) before the demand is totally exerted; or flushing by currents can disperse the material, diluting the sediment concentration and reducing the duration of the demand.

The hopper dredge, because it is constantly moving, impacts discrete locations for only a short period of time; however, its effects cover a wide area. The sessile clamshell or hydraulic cutterhead dredge inversely impact only a limited area at one time, but effects are exerted continuously. Dissolved oxygen reductions caused by the continual introduction of oxygen consuming materials can last the duration of the project.

Sediment Loading. Suspended solids loading caused by the hopper dredge is characterized by plumes generated from two sources. The dragheads are a continual source of resuspension during the cutting operation. Intermittently, a second plume is introduced during overflow. These plumes begin to merge almost immediately astern of the dredge. A homogeneous solids distribution is not typically achieved vertically for one or two hundred meters downstream. This distance can be extended or shortened by variations in current velocity. At the draghead initial disturbance of the sediment can cause the loading to exceed 2.5 g/l. During this investigation, the concentration generally decreased to less than a half gram per liter within a hundred meters downstream. Initial sediment loading in the upper water column astern of the overflow ports averaged 3.5 g/l. This concentration was diluted almost immediately such that a solids level of less than a half gram per liter was found at 50 meters downstream. When these two plumes were being generated simultaneously, solids concentrations above ambient were detected up to 800 meters downstream and 150 meters laterally.

The clamshell monitoring indicated that it also generated two plumes. The disruption of the bottom by bucket impact and subsequent resuspension during its removal created a bottom to mid-water plume. This plume had sediment concentrations of several hundred milligrams per liter and could extend as much as 500 meters downstream and 75 meters laterally. A second plume was observed at the surface. This plume resulted from spillage when the loaded bucket broke the water's surface. Concentrations of a hundred milligrams per liter or more were observed to influenced water quality to approximately 300 meters downstream.

Within the "area of influence" sediment loading can fluctuate significantly depending on several factors. The sediments physical properties are the principal factors. Variations in the particle size distribution, percent moisture and degree of cohesion control the tendency of a sediment to be resuspended. Additionally, these properties influence the rate at which particulates settle. The salinity in the project area determines whether flocculation is a significant factor in fine sedimentation. Krone (1962) has shown that flocculation is initiated at salinities of one part per thousand. The amount of energy imported to the shoal is dependent on the type of equipment and how the operator handles the excavation. The more violent the "attack", the more particles resuspended. Loading is not uniform throughout the water column. It is contingent on the location in the water column where disturbance and introduction occur. Each of the three types of dredges utilized in San Francisco Bay (the trailing suction hopper dredge, the clamshell dredge, and the hydraulic cutterhead dredge) disturbs the sediment in a different manner. Table 10 lists the operations of each of the three types contributing to sediment loading.

TABLE 10

OPERATIONS CAUSING SEDIMENT LOADING

Vessel Type	Vessel Movement	Time of Operation	Cutting	Lifting thru Water	Loading
Trailing Suction Hopper Dredge	Yes	Intermittent (about 1 hr. cycle)	Yes	No	Yes
Clamshell Dredge	No	Continuous	Yes	Yes	Yes
Hydraulic Cutterhead Dredge	No	Continuous	Yes	No	No

The trailing suction hopper dredge, because of its size and means of propulsion, is the only one of the three dredges that disturbs the bottom material as a result of vessel passage and prop-wash. However, this phenomenon is not unique to a hopper dredge, but occurs whenever a vessel with a relatively deep draft uses a channel. All three dredges cause agitation of the sediments during the cutting operation. The hopper dredge disrupts the bottom sediments when its two trailing drags pass though the shoal material. The clamshell dredge disturbs and re-suspends bottom material as the bucket bites into the sediment and breaks free upon being hoisted. The hydraulic cutterhead dredge is continually resuspending sediments as long as the cutter is crowding the sediment face. Not all of the sediments being suspended by the hydraulic cutterhead are drawn into the suction pipe; varying amounts are be carried away by currents. The pipelines of the cutterhead and hopper dredges reduce disturbance in the water column as the sediments are moved from the Bay floor to the surface. In contrast, the bucket of the clamshell dredge loses sediments as it is raised through the water column. These sediments continue to be lost during the loading operation as the bucket breakes free of the water surface and is swung to the dump scow or barge. Gordon (1973) estimated losses to be about 2.5 percent of the material lifted. Water charged with particulates re-enter the water colum when water is intentionally displaced from the scow or when inadvertent spillage occurs. Similarly, the hopper dredge discharges particulates during overflow periods. These overflow periods in the loading of both the hopper and the barge are intended to displace the water in the vessels with solids. This is to obtain the highest economical solids density. Site conditions also influence the nature and duration of loading. Site conditions of importance include the sediment characteristics as previously discussed, depth or face of the cut, spacing and shape of the dredging areas and restrictions. Restrictions placed on the type of dredging equipment which may be used in certain areas, although not a common factor, can significantly influence the degree and/or the duration of disturbance. The type of equipment for the channel dredging over the Alameda Tubes in Oakland Inner Harbor, for example, is limited to the hopper dredge to insure that dredging operations do not damage the tunnels. The length and shape of the cut over the tubes decreases the operating efficiency of the drag arms of the hopper dredge, thereby increasing the amount of water pumped and, in turn, increasing the overflow from the hopper. Finally, the system's natural energy is a factor in determining loading, particularly as influenced by dispersion. Dispersion increases as the velocity of tidal and wind induced currents increase.

Although all these factors are important they are secondary to the control exerted by the sediment's physical properties. The type of sediment (i.e., sand versus silt or clay) and the water content of the sediment are the primary parameters used to determine the degree of sediment

loading. These parameters influence the duration of the interaction, that is, the time required for particles to settle out of the water column. Without flocculation, a large portion of the fine sediments would remain suspended indefinitely in the water column. In addition, as the sediments aggregate and concentrate in the lower water column, the rate of settling decreases because particles interfere with one another. This phenomenon occurs at concentrations greater than 10 g/l and is referred to as "hindered settlin." It results in establishment of a fluff zone or unconsolidated layer at the sediment-water interface. Figure 24 illustrates the hindered settling phenomena in terms of settleable material with time. In San Francisco Bay, the fluff condition more commonly occurs and is more persistent in dredged channels than in disposal areas. This is because current energy and configuration are different. The high current velocity and openness of disposal sites tend to prohibit their formation by dispersing the sediments before sufficient concentrations collect for layer formation. The fluff layer can be established after about one week of dredging and will continue to exist within the confines of the channel for a few weeks beyond termination of the dredging operation. Limited information shows that the fluff is an ill-defined bottom and varies from about two grams of suspended solids per liter ot 450-500 grams per liter in situ (the upper layer of relatively undisturbed bottom sediments). Filling of the tidal prism through bottom water and emptying in surface waters as occurs in many of the dredging projects (e.g., Mare Island Strait, Oakland Harbor, Richmond Harbor and Alameda Naval Air Station) can cause the fluff material to remain in the dredging site and resist flushing by tidal action. Typically, within about a two-week period after dredging, the fluff material will settle in the channel and become somewhat more compacted. This unconsolidated layer has been reported in dredged channels by other investigators (Simmon, 1966; Masch and Espey, 1967).

Interactions During Disposal

Chemical Reactions. Monitoring during disposal indicated that neither salinity/conductivity, temperature nor pH were significantly influenced by the operations. Release of bottom sediments from hopper dredges was found to produce both significant increases and decreases in the dissolved oxygen concentration of the water column. The direction and magnitude of dissolved oxygen fluctuations associated with release is primarily dependent on the chemical composition of the sediment and on the amount of mechanical perturbation associated with dredge operation. The sediments disposed in Carquinez Straits had a mean chemical oxygen demand (COD) of 4.43% dry wt. whereas the sediments disposed at the San Pablo Bay site had a mean COD of 2.07% dry wt. The difference in the demand for oxygen exerted by the material was at least partially

HINDERED SEDIMENT SETTLING

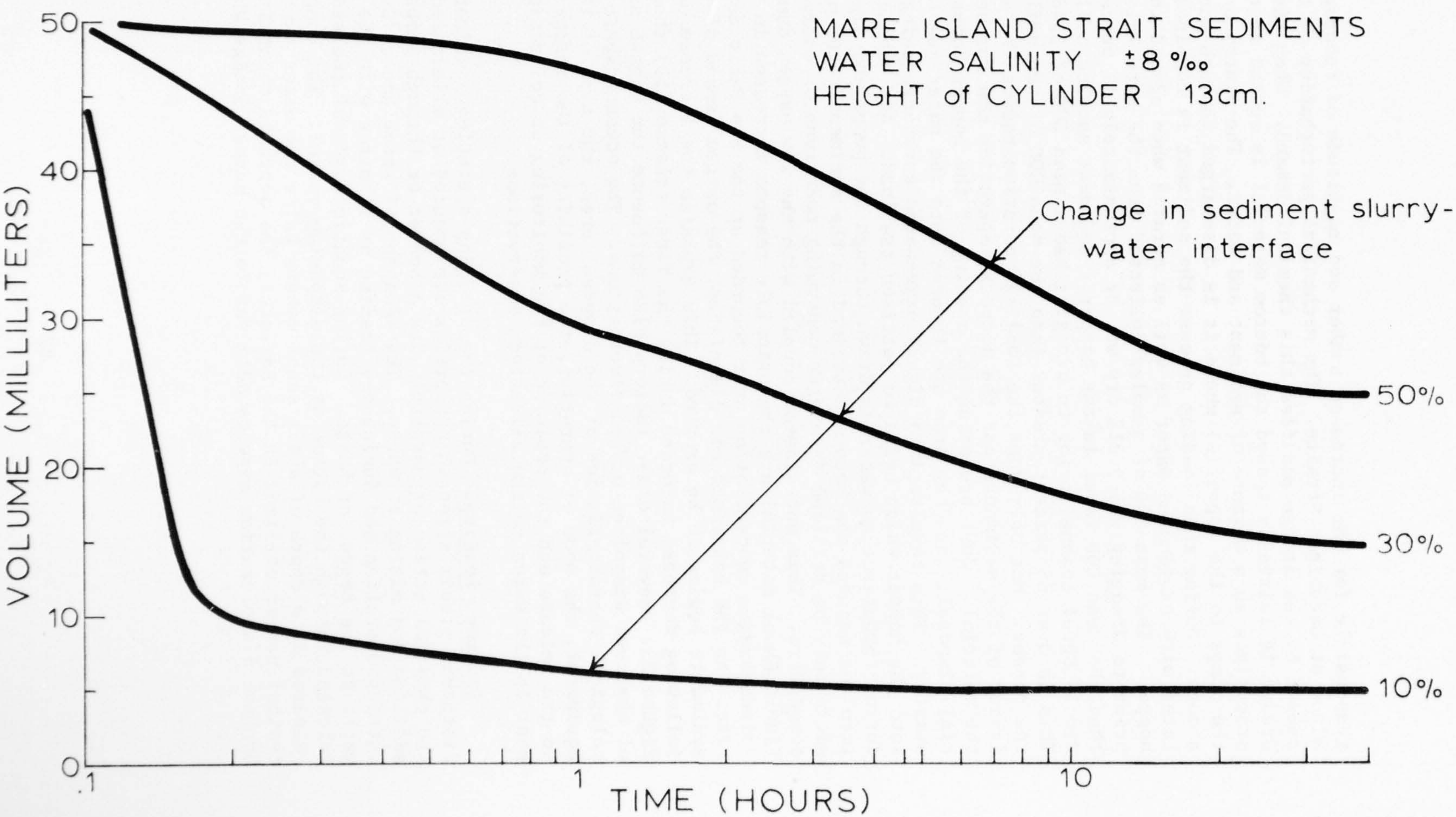


FIGURE 24

responsible for the increased number and magnitude of recorded depressions at Carquinez Straits. The mechanical perturbation of the sediment caused by the dredge modifies this chemical demand. When the hopper dredge is initially loaded the bottom material is sucked up through the drag pipes as a mixture of sediment and water. The slurry proceeds via the pumps to the hopper(s) where it is discharged through one or several shoots. During this loading process the sediment is combined and agitated with oxygenated water as well as aerated when spewed into the hopper. The mean COD of samples collected from the Mare Island channel prior to dredging was 5.21% dry wt. or approximately 17 percent greater than the mean COD level in the hopper. Sediment samples collected in Pinole Shoal channel prior to dredging had a mean COD of 3.48% dry wt. This is over 68 percent greater than the mean COD of the sediments in the hopper. Not only does the loading operation reduce the oxygen demand of the sediments but the disposal operation can further aerate the material. Just preceding the opening of the hopper doors and material disposal, the drag arms are lowered into the water and the pumps started. This results in a highly oxygenated surcharge being introduced into the hopper which helps to jettison the load. Air bubbles created during turbulence as water is drawn through the pumps and discharged into the hoppers can become entrained in the sediment/water mixture to ultimately be utilized in oxygen consuming reactions or escape to the atmosphere. This entrainment coupled with the low oxygen demand of the Pinole Shoal material are the principle reasons increases in the dissolved oxygen concentration were recorded at the San Pablo Bay disposal site. As the entrained air diminishes, the oxygen demand of the anoxic sediments begins to be exerted. This explains the increase and the following decrease recorded during the first release (1D) shown in Figure 23. Several other factors also influence the degree and duration of observed dissolved oxygen fluctuations. The oceanographic and climatological characteristics of the disposal area, the type of the disposal equipment, the mode of operation, the proximity of the research vessel to the release and the position of the monitoring or collection equipment in the water column all affect observations.

Sediment Loading. During the dredging operation, sediments are disturbed (their strength properties are reduced or eliminated) due to the physical action of handling with a bucket or through pumps and the addition and mixing of water. The addition of water occurs during the cutting operation and during the loading as it mixes with the residual water in the hopper or barge. During aquatic disposal the sediments are released through the bottom of the disposing vessel. The hopper dredge releases at a depth of about seven meters below the water surface. For typical barges utilized in the Bay area, the depth is about five meters. Surface discoloration appears adjacent to the hopper dredge when the

pumps start just prior to the release (pumping adds water to the hopper resulting in overflow). Surface discoloration also appears when the suspended solids remaining after the sediments pass through the water column are agitated by the passage of the vessel. The suspended solids concentrations of the most turbid water on the surface during a typical disposal are shown on Figure 10 at Station Z. With Bay mud, the water content of the sediment and the degree of disturbance to the sediment during dredging are the controlling factors in determining the dispersion pattern of the sediments as it passes through the water column. Laboratory simulation studies (Appendix M, Dredging Technology) have indicated that minimally disturbed sediment with a water content at the in-channel level (e.g., sediment clumps from a clamshell operation) will pass through the water column and mound temporarily on the bottom. The slurry associated with the clumps in the clamshell and with the hopper dredge operation will pass through the water column, relatively intact, and upon impact with the bottom, develop a density flow or turbidity cloud confined to the bottom. Total suspended sediment concentration in the water column from the surface to the top of the cloud (estimated to be no more than a couple meters off the bottom) is about one to five percent of the total sediments in a hopper or barge load, depending on the dredging conditions and the disposal site.

The dredge material released at a disposal site possesses an initial downward momentum and a density greater than that of the surrounding water (Gordon, 1974). These factors result in forces that cause the material to settle in the form of a cloud, or density current, rather than settle as individual particles. This is called the convective descent phase and occurs very rapidly (Clark _et al_, 1971). Settling velocities calculated for individual particles do not apply during this form of transport. The time during which the cloud is in contact with the upper portions of the water column is in the order of a minute or less. Thus, ambient water currents, except near the bottom, are of little consequence in dredge material placement (Gordon, 1974). Currents are important as they affect the transport of the turbidity cloud that may be generated during the descent. Such a cloud is formed by overflow just prior to release and by disturbance due to the prop wash, the vessel passing through the site, and by the shear stresses developed at the interface between the descending material and the ambient water. These stresses result in dissipation of the initial momentum and in the creation of turbulent eddies that entrain water and result in spinoffs from the main cloud. The sediment in the upper water column represents a very small percentage of the total mass (1 to 5 percent).

The second phase of transport occurs when the cloud begins a dynamic vertical collapse, characterized by horizontal spreading upon contact with the bottom (Clark, _et al_, 1971). Collapse is driven primarily by a pressure force, and resisted by inertial and frictional forces. The material flattens out and is similar to the base surge cloud in underground detonations as it assumes a horizontal circular shape with a small vertical dimension.

Since the hopper dredge HARDING has two hoppers, the twin injection results in two plume fronts moving toward and away from each other. The plumes act as fluid muds with mean concentrations of about 10 g/l. Each plume interface moves progressively out of the disposal area as a density flow Gravity, inertia and the density gradient provide the dominant driving forces. In addition, the slope of the bottom at the Carquinez Strait is steep enough to maintain the fluid flow. Currents have very little effect on transport initially. They are overshadowed by the effect of the density gradient between the surrounding water and the sediment mass and the sloping bottom. The effect of the slope causes the two divergent wave fronts to be altered from a predicted concentric pattern to a skewed pattern down slope and a compressed pattern up slope. The merging wave fronts between the two hoppers collide and generate a new or secondary wave front which moves off perpendicularly to the axis of collision (see figure 25). The perpendicular movement is caused by the generation of a new vector following the interaction of colliding plume wave front vectors. The primary and secondary wave fronts can interact with each other in three ways. First, readings indicate a single, unamplified peak (wave front) which does not reflect any enhancement from another wave front. Second, two peaks indicating two wave fronts can be observed. They augment each other and thus increase the total suspended solids concentration at an instantaneous place and time. Third, a single amplified peak can be observed when the two wave fronts are in-phase. Using station 4, Figures 16-21, as an example, the first situation (single, unamplified) was observed during release number one. The second situation (double, amplified but not synchronous) was observed during release number six, and the third (single, amplified) during release number seven. The interaction of a twin injection is shown in photographs 11, 12 and 13.

The maximum observed concentrations (reinforced peaks) at several distances were used to develop a hypothetical curve delineating horizontal decay of the plume front (see figure 26). The curve indicates that the plume could travel as far as 1400 meters down-current before decaying to near ambient solids level (approximately 0.2 g/l at a depth of 12 meters). The mean duration of increased solids concentrations at a single point is approximately 17 minutes. The concentration curve at a single point generally follows a skewed (right) shaped distribution during this time period, such that there is a rapid initial increase in solids, followed by a much longer period of solids decrease.

Initially, the velocity of the wave front is less than the current velocity (i.e., the cloud velocity was approximately 0.2 to 0.3 meter per second slower than the current velocity at 90 meters from the release point). As the wave front progresses outward, the solids content decreases because of water entrainment and deposition. At the same time that the flow's density is decreasing, its velocity is increasing (i.e., at 750 meters the wave front was moving at 0.1 to 0.2 meter per second faster than the current).

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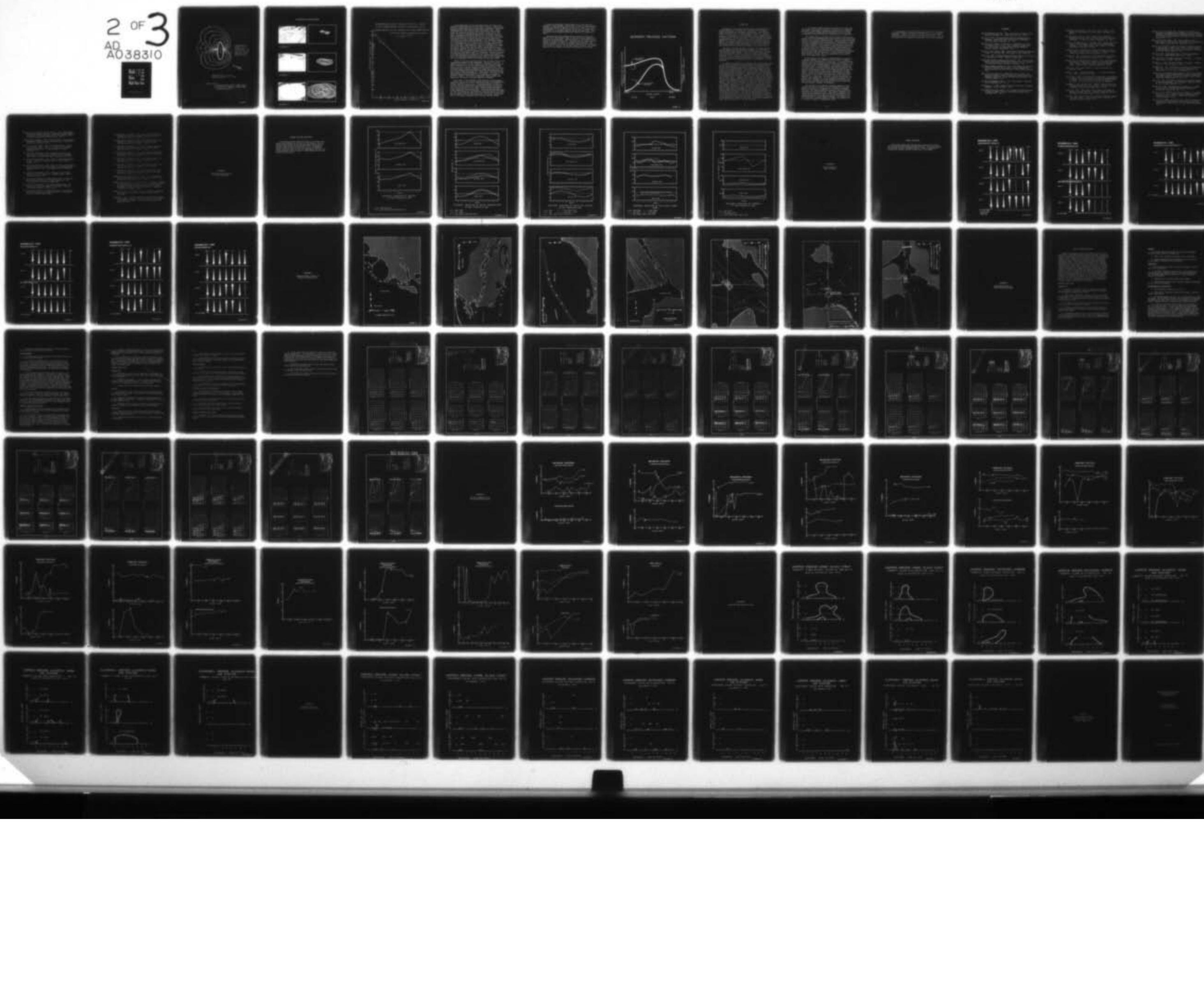

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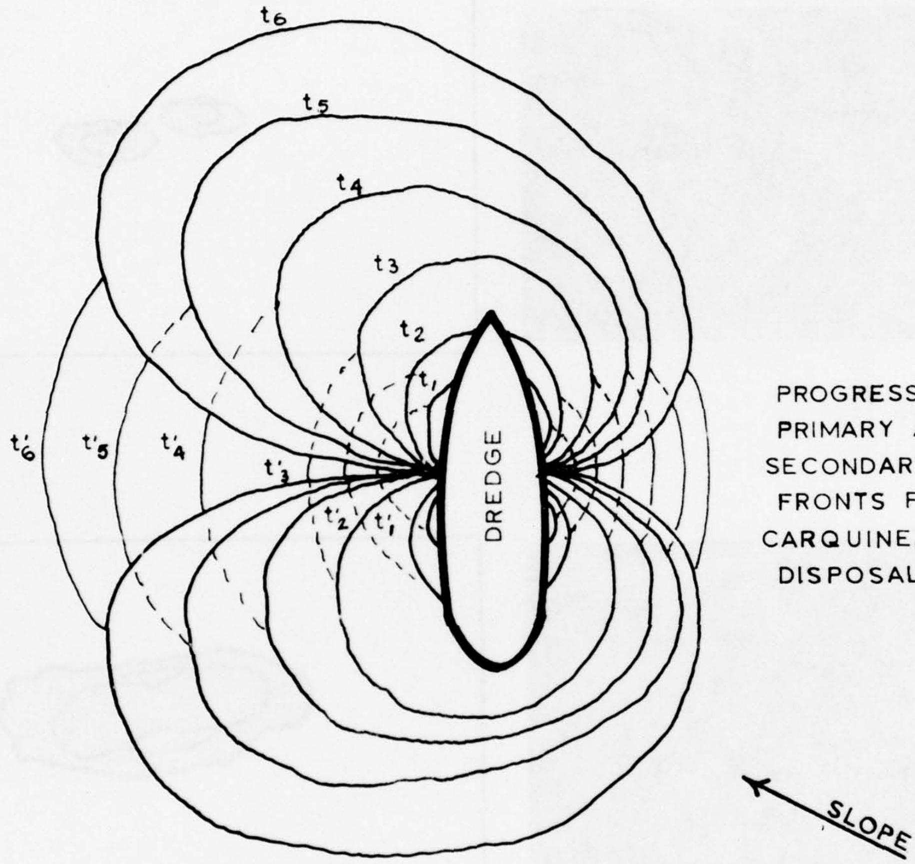


PROGRESSION OF PRIMARY AND SECONDARY PLUME FRONTS FROM THE CARQUINEZ STRAIT DISPOSAL SITE

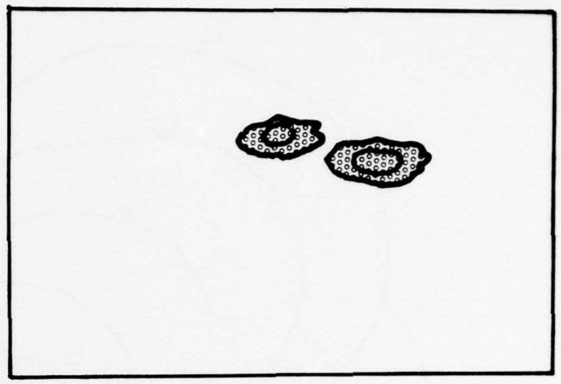
PRIMARY WAVE t=1, 2, 3 etc.
SECONDARY WAVE t'= 1, 2, 3 etc.

SLOPE CAUSES:

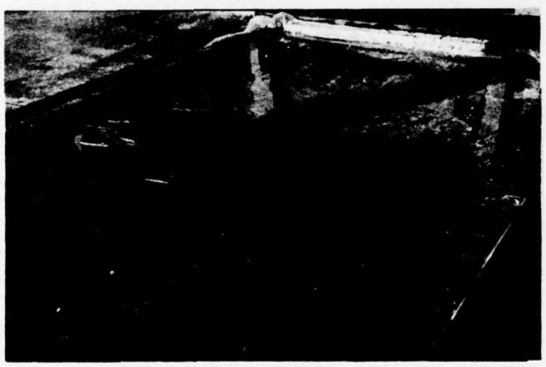
a) COMPRESSION OF UPHILL WAVE FRONT
b) SKEWNESS OF DOWNHILL FRONT AND INCREASES VELOCITY

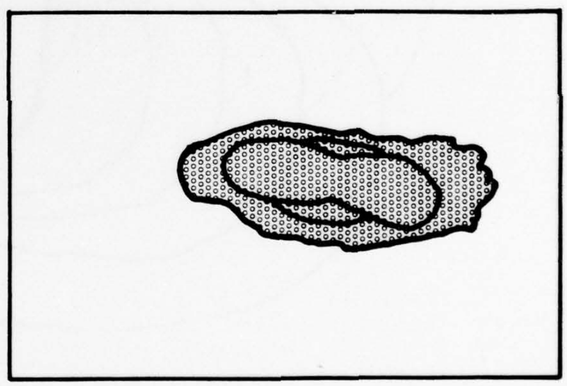
FIGURE 25

INTERACTION OF TWIN INJECTION

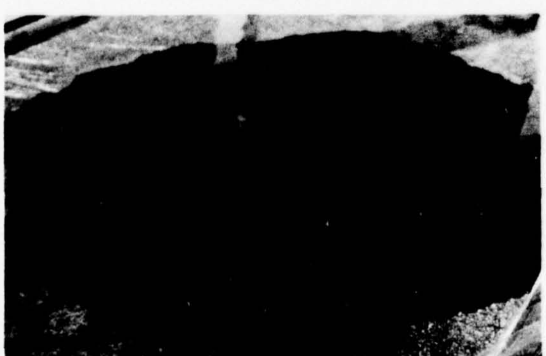


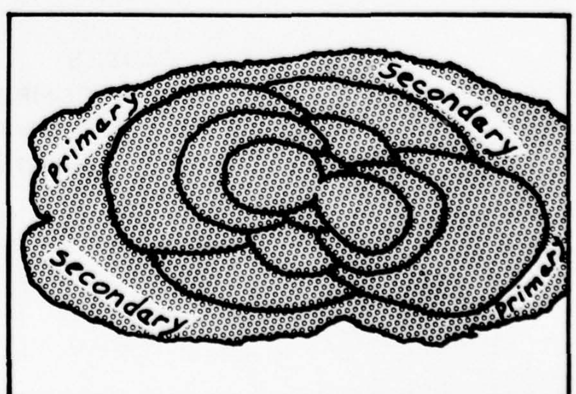
PHOTOGRAPH 11





PHOTOGRAPH 12





PHOTOGRAPH 13

SUSPENDED SOLIDS CONCENTRATION DECAY
from CARQUINEZ STRAIT DISPOSAL SITE
(Hypothetical Curve Generated from 1975 Data)

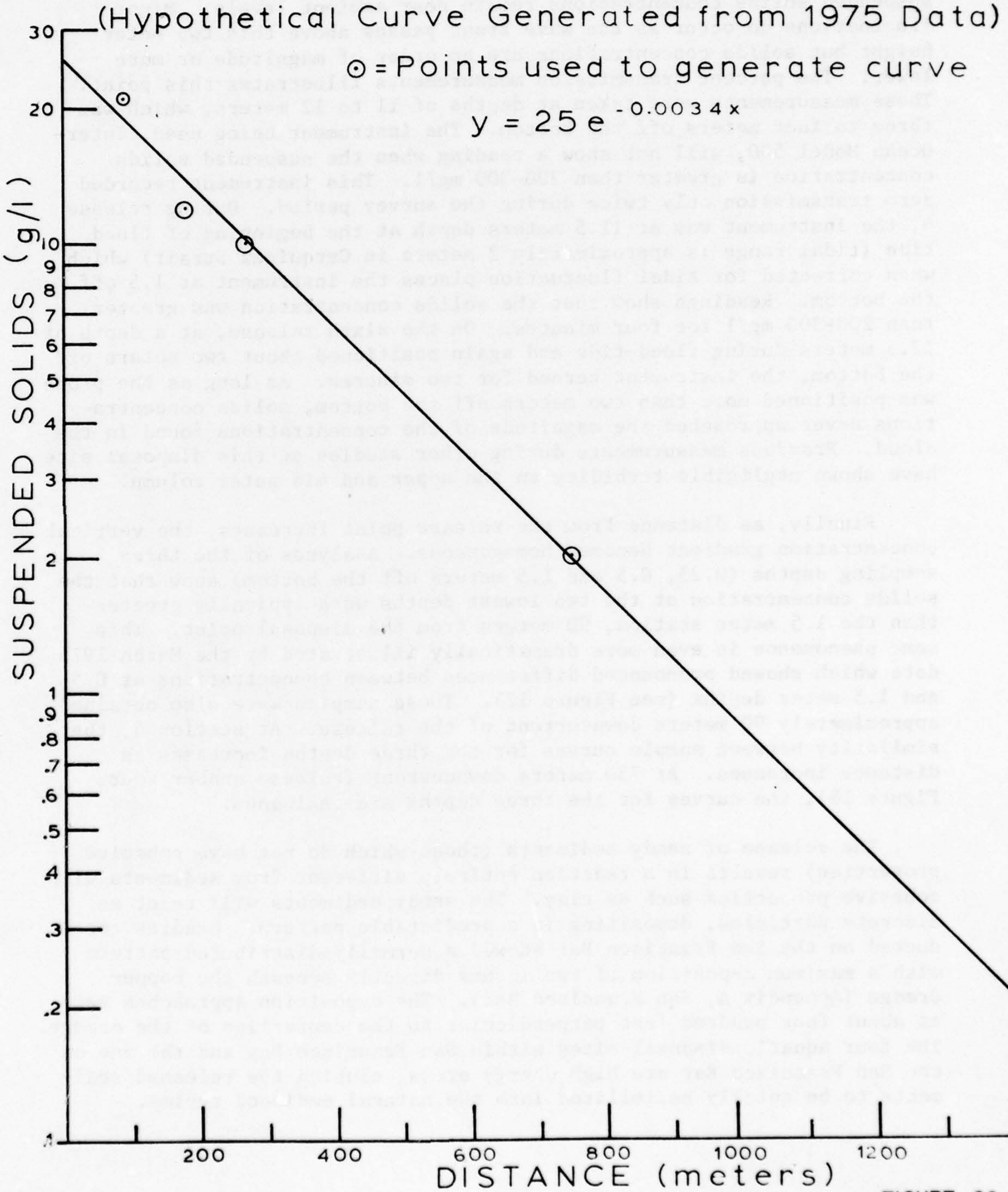


FIGURE 26

As the plume moves out from the release point, the cloud is essentially confined essentially to the lower two meters of water column. Above the bottom surge cloud, the water mass is negligibly affected and suspended solids concentrations remain near ambient levels. Minor fluctuations do occur as the wave front passes above this two meter height but solids concentrations are an order of magnitude or more lower. The percent transmission measurements illustrates this point. These measurements were taken at depths of 11 to 12 meters, which was three to four meters off the bottom. The instrument being used, Inter-Ocean Model 500, will not show a reading when the suspended solids concentration is greater than 200-300 mg/l. This instrument recorded zero transmission only twice during the survey period. During release 4, the instrument was at 11.5 meters depth at the beginning of flood tide (tidal range is approximately 2 meters in Carquinez Strait) which when corrected for tidal fluctuation places the instrument at 1.5 off the bottom. Readings show that the solids concentration was greater than 200-300 mg/l for four minutes. On the sixth release, at a depth of 12.5 meters during flood-tide and again positioned about two meters off the bottom, the instrument zeroed for two minutes. As long as the probe was positioned more than two meters off the bottom, solids concentrations never approached the magnitude of the concentrations found in the cloud. Previous measurements during other studies at this disposal site have shown negligible turbidity in the upper and mid water column.

Finally, as distance from the release point increases, the vertical concentration gradient becomes homogeneous. Analyses of the three sampling depths (0.25, 0.5 and 1.5 meters off the bottom) show that the solids concentration at the two lowest depths were typically greater than the 1.5 meter station, 90 meters from the disposal point. This same phenomenon is even more dramatically illustrated by the March 1975 data which showed pronounced differences between concentrations at 0.5 and 1.5 meter depths (see Figure 12). These samples were also obtained approximately 90 meters downcurrent of the release. At station 4, the similarity between sample curves for the three depths increases as distance increases. At 750 meters downcurrent (release number four, Figure 18), the curves for the three depths are analogous.

The release of sandy sediments (those which do not have cohesive properties) results in a reaction entirely different from sediments with cohesive properties such as clay. The sandy sediments will react as discrete particles, depositing in a predictable pattern. Studies conducted on the San Francisco Bar showed a normally-distributed pattern with a maximum deposition of two inches directly beneath the hopper dredge (Appendix A, San Francisco Bar). The deposition approaches zero at about four hundred feet perpendicular to the centerline of the dredge. The four aquatic disposal sites within San Francisco Bay and the one on the San Francisco Bar are high energy areas, causing the released sediments to be quickly assimilated into the natural sediment regime.

During the monitoring of ocean disposal at the 100-fathom site (Appendix L, Ocean Disposal), Bay mud with clamshell dredging and barge transport was observed to mound on the bottom in clumps. The controlling parameters in the release pattern are the type of sediment and the disturbances to the sediment caused by adding and mixing water. This was shown by field studies and laboratory simulation of release patterns.

Utilizing these field findings and the laboratory finding from Appendix M, for the different types of material and their mounding and dispersion characteristics, a theoretical model of the sediment release pattern was developed (Figure 27). The model uses the liquid limit of a sediment to predict the degree of mounding verses dispersion. With cohesive sediments, two curves are necessary because of the influence of water content on cohesion. As the water content increases, the cohesive properties of the sediment are reduced and dispersion is increased.

SEDIMENT RELEASE PATTERN

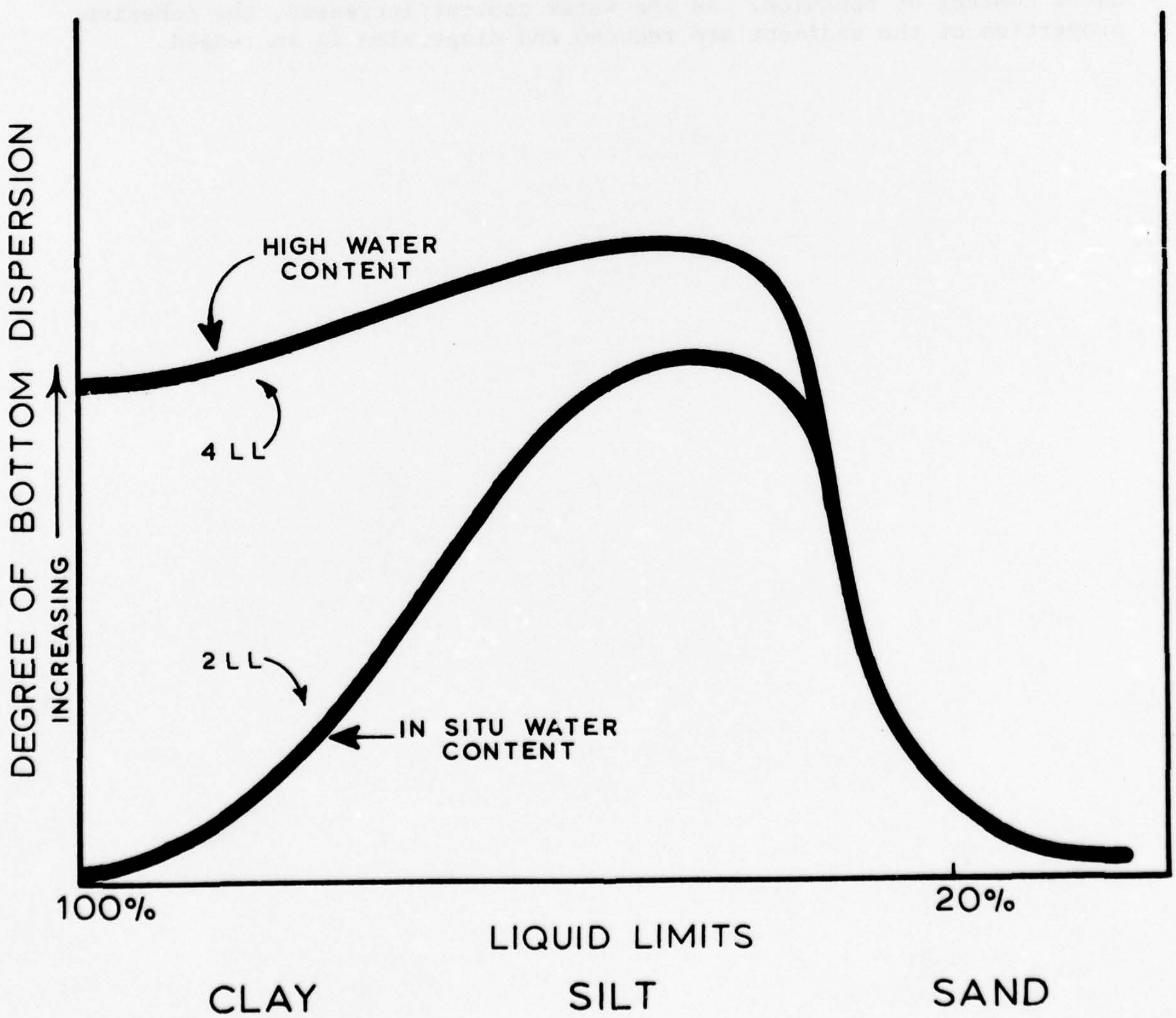


FIGURE 27

CONCLUSIONS

Assessment of actual water quality changes during dredging and disposal operations is essential for interpretation of biological studies and prediction of biological ramifications. This four-year study found field data to be highly variable because of a variety of factors. At other times, it is unobtainable. Thus, integration and evaluation of findings can not be made from absolute numbers predicated on field results. The best alternative is to use the mean and maximum magnitude and duration of observed water quality aberrations for assessment in a specific location. The lack of a homogeneous milieu in which to use absolute numbers emphasizes the logic of this approach. The estuarine system has intrinsic seasonal, areal and vertical variability which must be accounted for during the evaluation process.

The effects considered during an assessment of dredging and disposal operations stem from the induced sediment-water interactions. These reactions can be separated into two broad categories: chemical reactions and sediment loading. During this study, investigation of resulting chemical reactions was limited to standard water quality parameters. Exotic parameters (heavy metals, chlorinated hydrocarbons, etc.) were examined in other Dredge Disposal Study elements. Sediment loading was particularly emphasized during this investigation of in-Bay operations.

a. Neither the dredging nor the disposal operation typically cause a significant fluctuation in salinity/conductivity, temperature or pH. Both activities influence the dissolved oxygen concentration. The effects of the dredging operation were considerably less severe than those of the disposal operation. Reductions during dredging were detected only one quarter of the time. At the surface, overflow from a hopper dredge caused a depletion of approximately two parts per million. The oxygen concentration returned to ambient within about two minutes. At the sediment-water interface reductions of as much as four parts per million were recorded. Background concentrations returned after approximately eight minutes. Disposal from a hopper dredge resulted in surface reductions of approximately 2 parts per million. They lasted for two minutes. This reduction was similar to the surface reduction caused by dredging, both in terms of intensity and duration. But, near the bottom, sediment disposal can cause a significant oxygen depletion with each release. Reductions of up to six parts per million were observed. Ambient concentrations were regained after an average of three to four minutes. They could be influenced for as long as eleven minutes. During disposal operations in San Pablo Bay, oxygen increases did not exceed one part per million. The direction and intensity of these fluctuations is controlled by the chemical composition of the material, by its contactable surface area and by aeration resulting from mechanical perturbations during the operation. The duration of a dissolved oxygen reduction is controlled by the contact time between sediment and water and by the intensity of its initial demand.

b. The sediment loading created by dredging is different than that caused by the disposal operation; thus, each must be evaluated separately. Additionally, the physical properties of the material to be disturbed or released must be evaluated to predict the kind of interaction which will take place during each of the operations.

The dredging operation differs from the disposal operation principally in that the suspended solids concentrations in the bottom plume generally are an order of magnitude lower. During dredging the loading caused by the disturbance of the bottom and lifting-loading activities increase the suspended solids concentration in increments of a tenth of a gram. Disposal, on the other hand, increases the concentration in the bottom water by tens of grams. Another difference is that increases in solids levels during dredging are confined basically to the channel and return to background levels within several hundred meters of the dredge, whereas increases at the disposal site influence areas outside of the site boundaries. Influences extend thousand meters beyond the impact zone. Both operations have very little effect on the upper water column.

During disposal the release of dredged sediments may result in a complete mounding of the sediments on the bottom or a complete dispersion of the sediments over a large area. The controlling parameters are the type of sediment and the degree of disturbance to the sediment during the dredging operation. The cohesive properties of the sediment control the interaction of the sediment particles and the water column. A cohesive sediment with little disturbance (introduction and mixing with water) will descend through the water and mound on the bottom with little, if any, disturbance to the water column. If the cohesive properties are reduced because of added water or higher silt content, the slurry will entrain water during the descent. It will form a base surge cloud on the bottom and disperse over a large area. Initially, currents and wind-wave conditions at the disposal site do not influence the movement of the density flow. Ultimately, as water entrainment reduces the unit mass, currents and wind-wave conditions will tend to control the long-term sediment transport and dispersion.

The evaluation of the physical conditions generated at the disposal site during a release requires information on the engineering properties of the sediment and on the type of dredging operation. The primary engineering properties are the grain size distribution and the liquid limit. With cohesive sediments, the release pattern (degree of initial dispersion or mounding) can be correlated with the liquid limit and the moisture content of the sediment generated by the dredging operation. The degree of initial dispersion or mounding depends on whether the sediments act as a solid, a liquid or a transitional slurry.

In conclusion, the actual intensity, duration and area influenced by sediment loading is different for dredging than it is for disposal operations. However, the nature of the interactions within either operation is primarily controlled by the same three factors: (1) sediment properties, (2) equipment and operation, and (3) site conditions.

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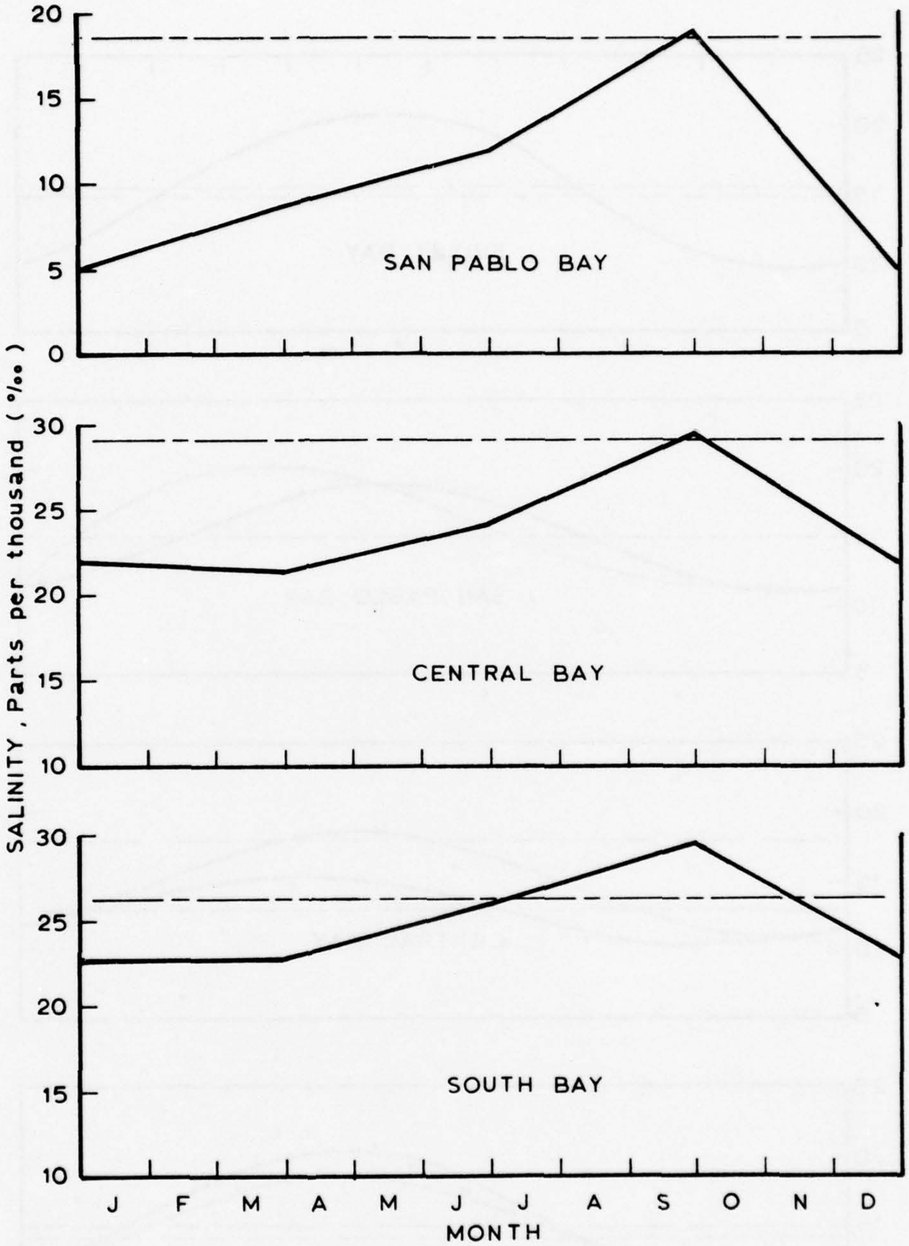
INCLOSURE 1

Seasonal and Areal Variations
in Water Conditions

SEASONAL AND AREAL VARIATIONS

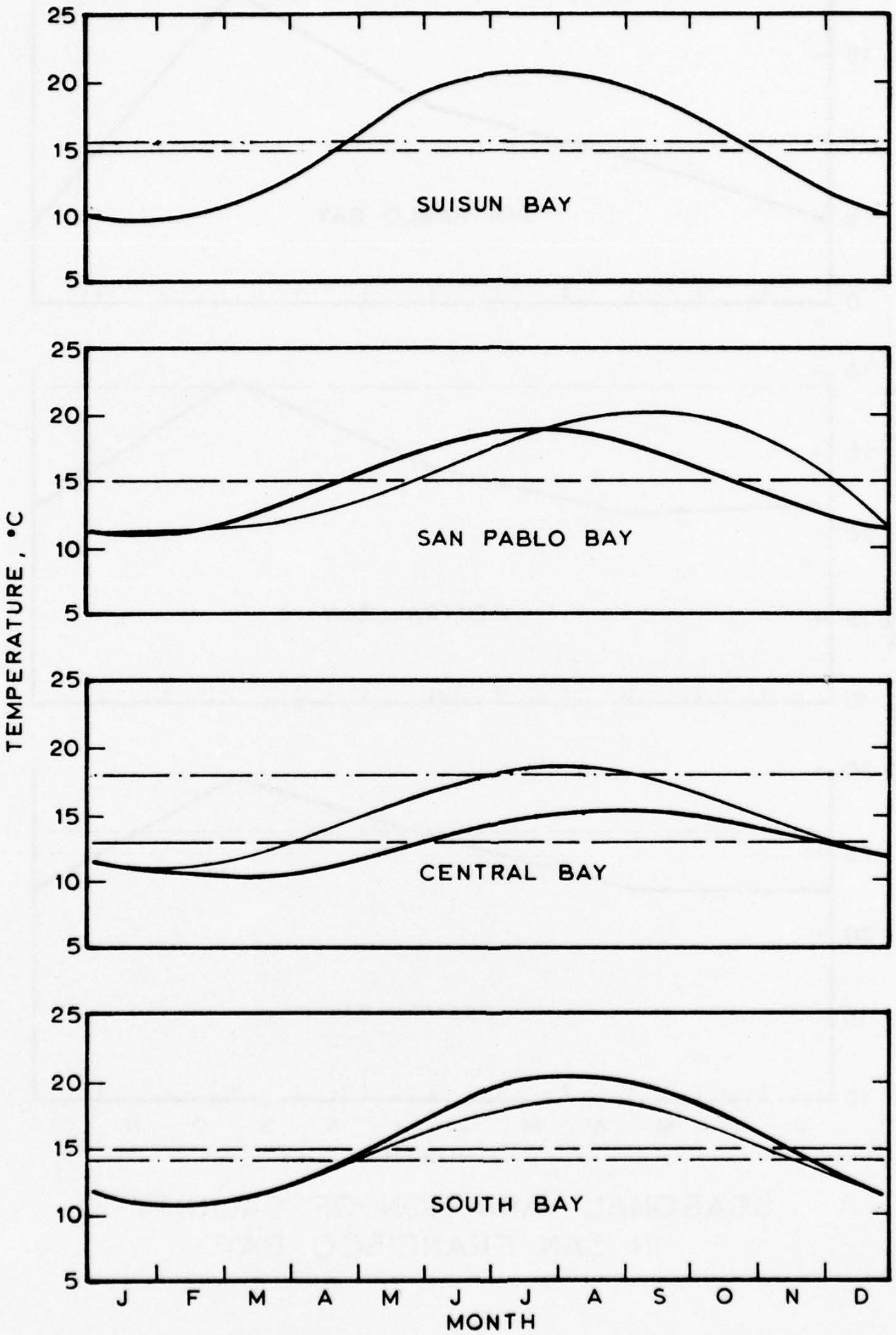
The following figures graphically display the seasonal water quality characteristics for each of the four sub-bays. This information was collected by the Sanitary Engineering Research Laboratory (SERL) during the period 1960 to 1964. Measurements during the period 1970 to 1975 were collected by the Stanford Research Institute (SRI) and have been supplemented with data from the Environmental Protection Agency's (EPA) STORET system for presentation in this report.



SEASONAL VARIATION OF SALINITY
IN SAN FRANCISCO BAY

SRI MEAN (1974)
SERL ESTIMATED MEAN (1960-1964)

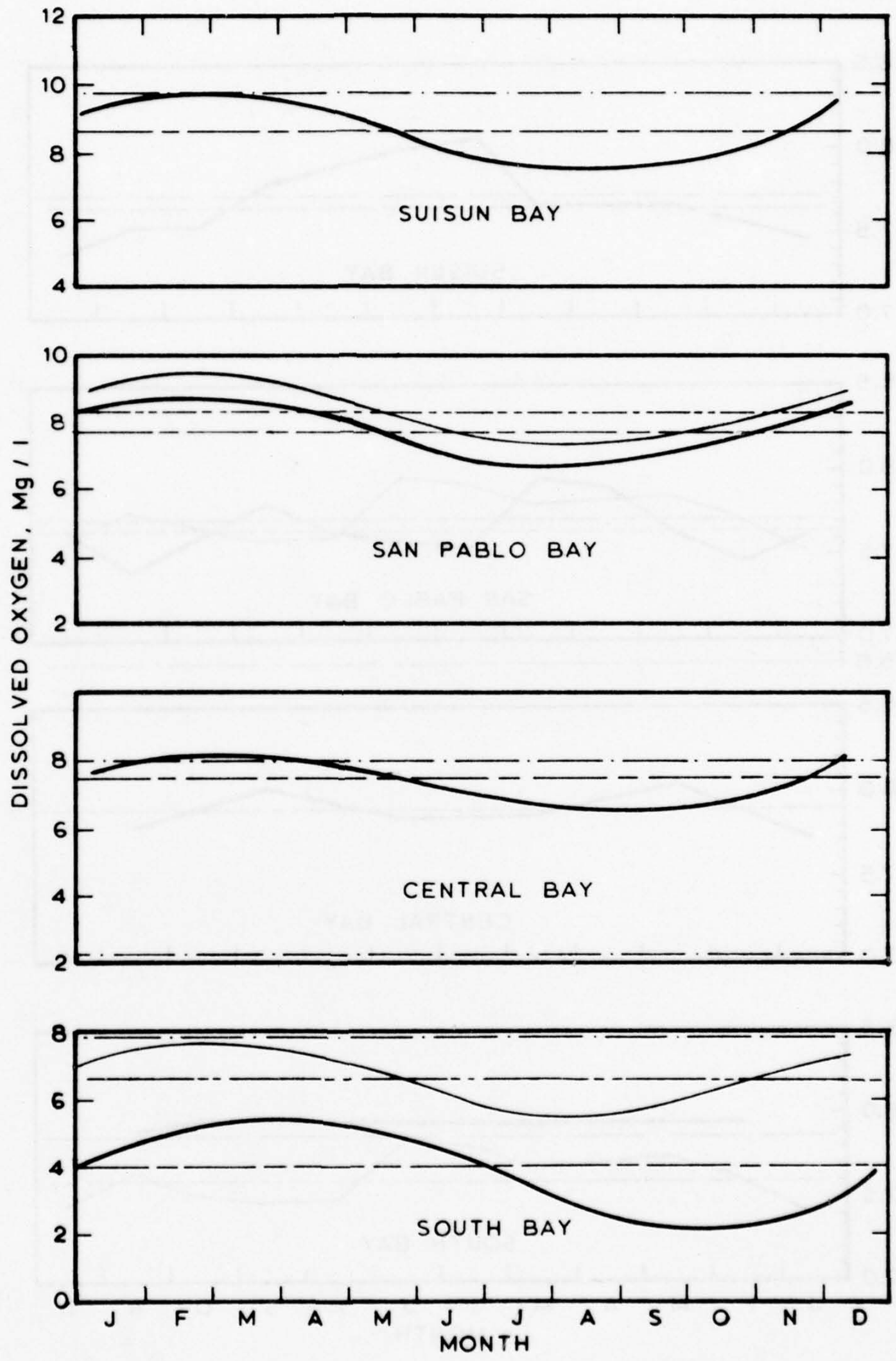
INCLOSURE 1-1



SEASONAL VARIATION OF WATER TEMPERATURE
IN SAN FRANCISCO BAY

——— SERL (1965)
——— SRI (1974)
—·— EPA STORET MEAN (1970-1975)

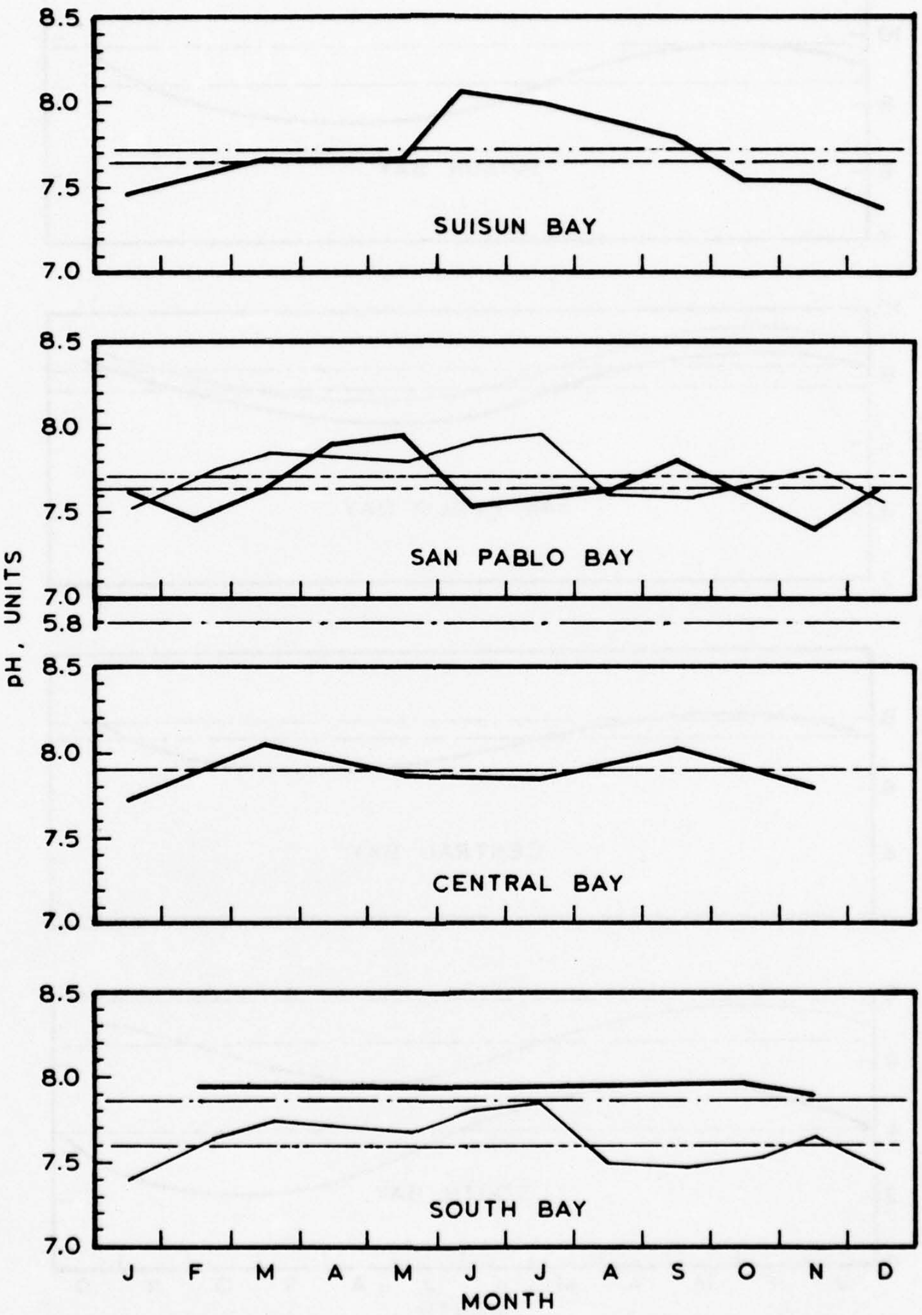
INCLOSURE 1-2



SEASONAL VARIATION OF DISSOLVED OXYGEN IN SAN FRANCISCO BAY

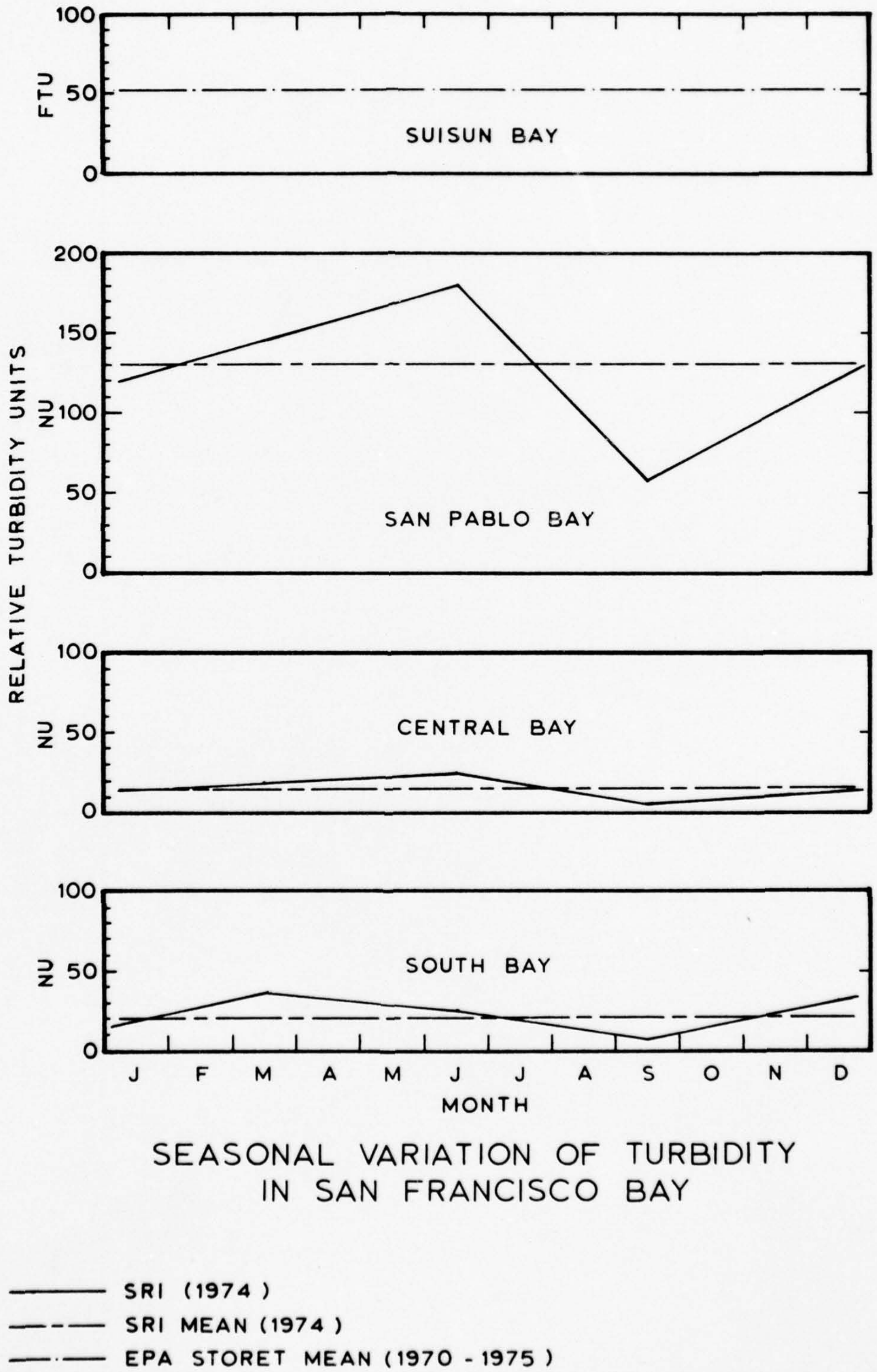
SERL — SERL MEAN (1965)
SRI — SRI MEAN (1974)
EPA STORET MEAN (1970-1975)

INCLOSURE 1-3



SEASONAL VARIATION OF pH IN EACH STUDY AREA

SERL (1965) — SERL MEAN
SRI (1974) — SRI MEAN
EPA STORET MEAN (1970-1975)



SEASONAL VARIATION OF TURBIDITY IN SAN FRANCISCO BAY

INCLOSURE 2

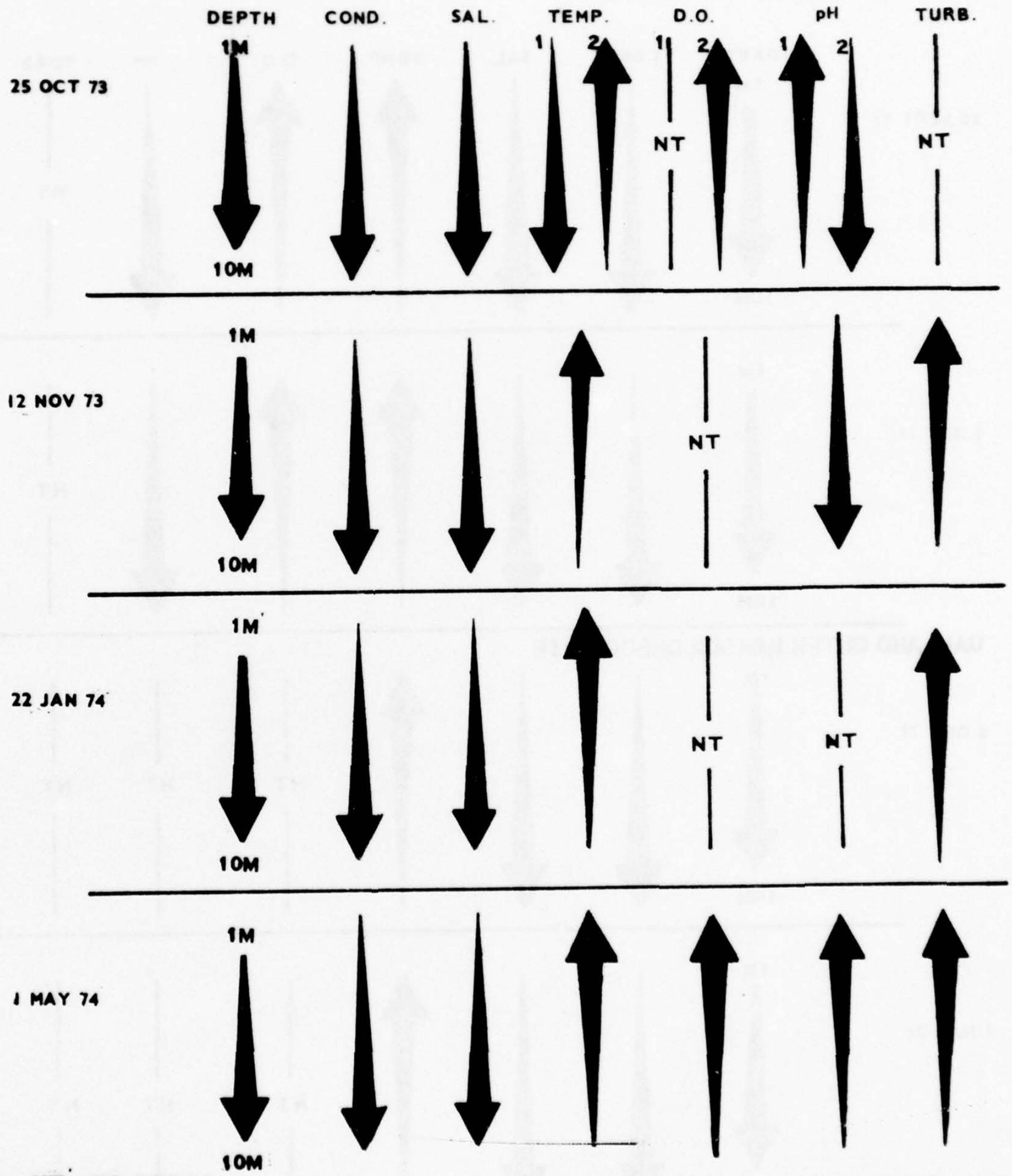
Vertical Trends in
Water Conditions

VERTICAL VARIATIONS

The inclosed figures were developed from available water quality data obtained during background monitoring periods. The arrows indicate the direction in which a parameter tends to increase in magnitude or concentration through a vertical profile from 1 to 10 meters.

BACKGROUND LEVELS – TRENDS

MARE ISLAND STRAIT DREDGE SITE

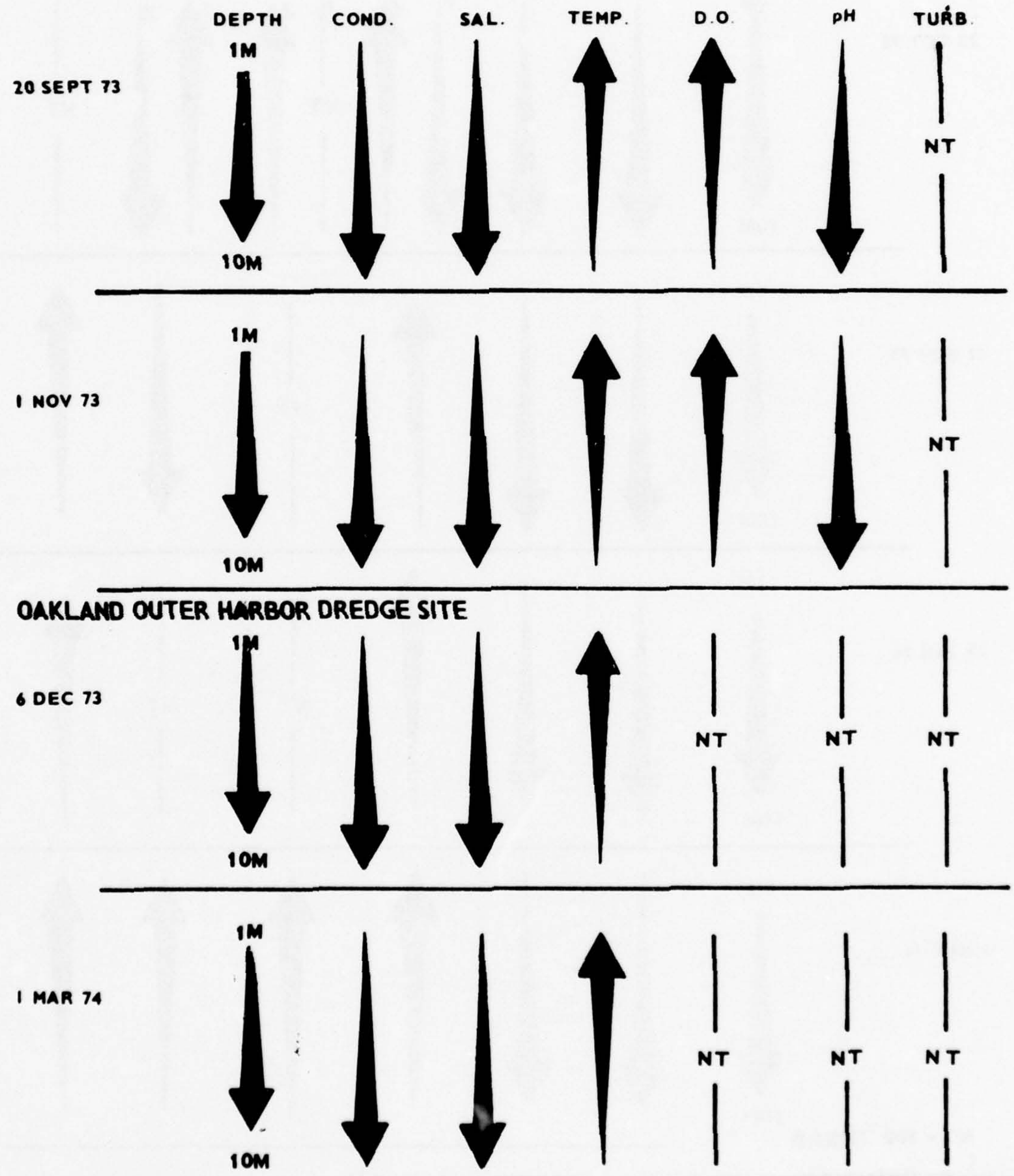


NT = NO TREND
[1] FLOOD TIDE
[2] EBB TIDE

INCLOSURE 2-1

BACKGROUND LEVELS – TRENDS

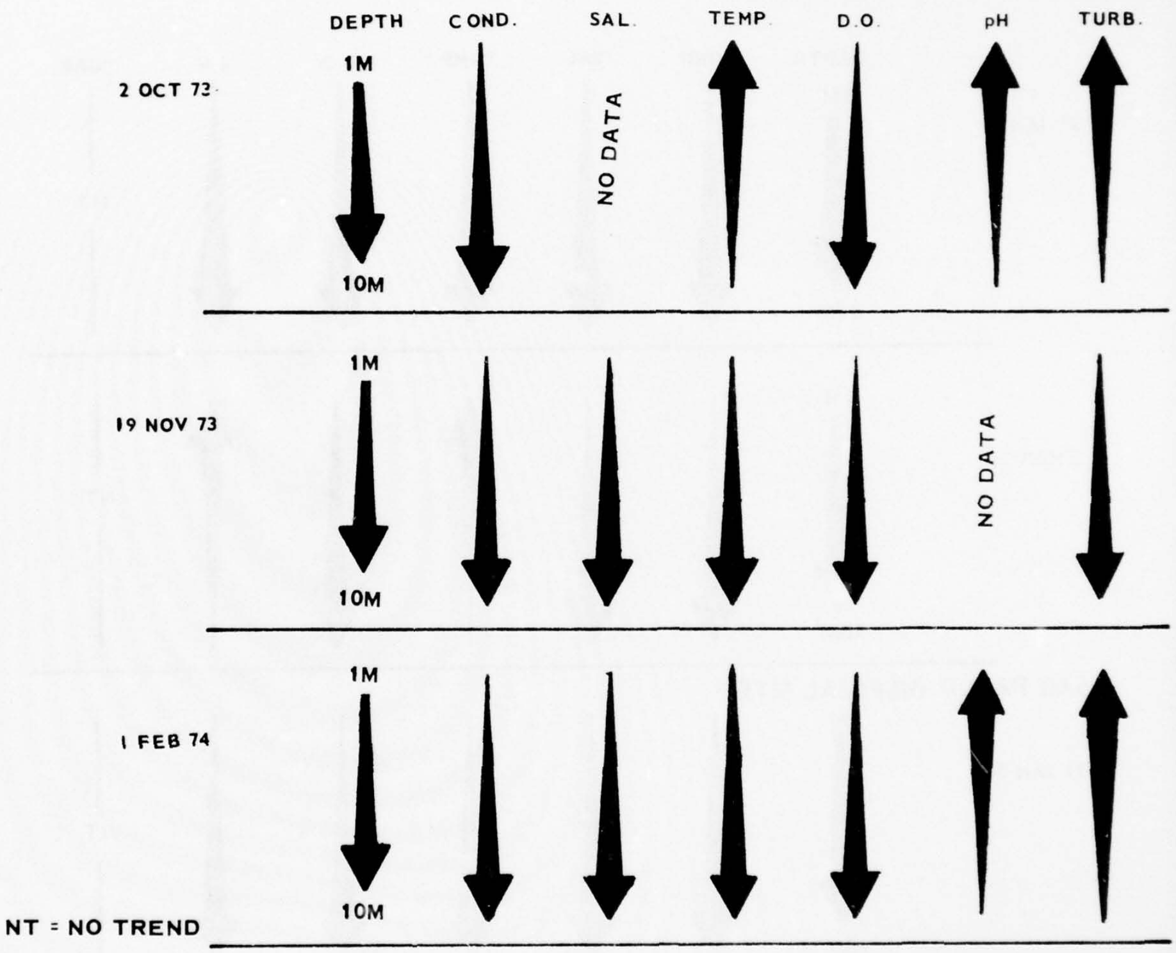
RICHMOND HARBOR DREDGE SITE



NT = NO TREND

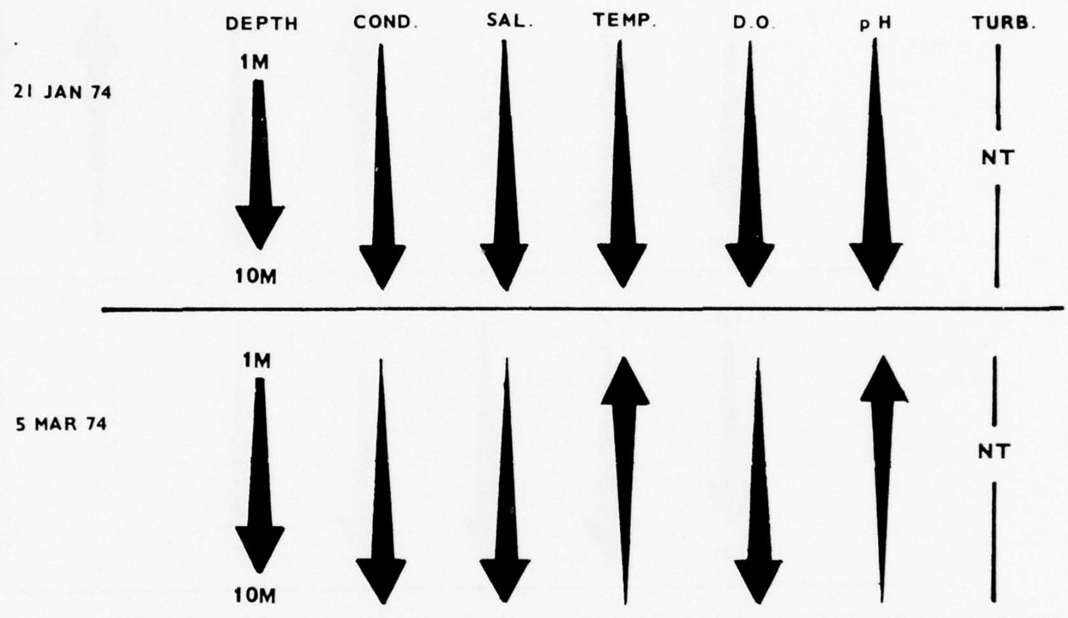
BACKGROUND LEVELS – TRENDS

ALAMEDA NAVAL AIR STATION DREDGE SITE

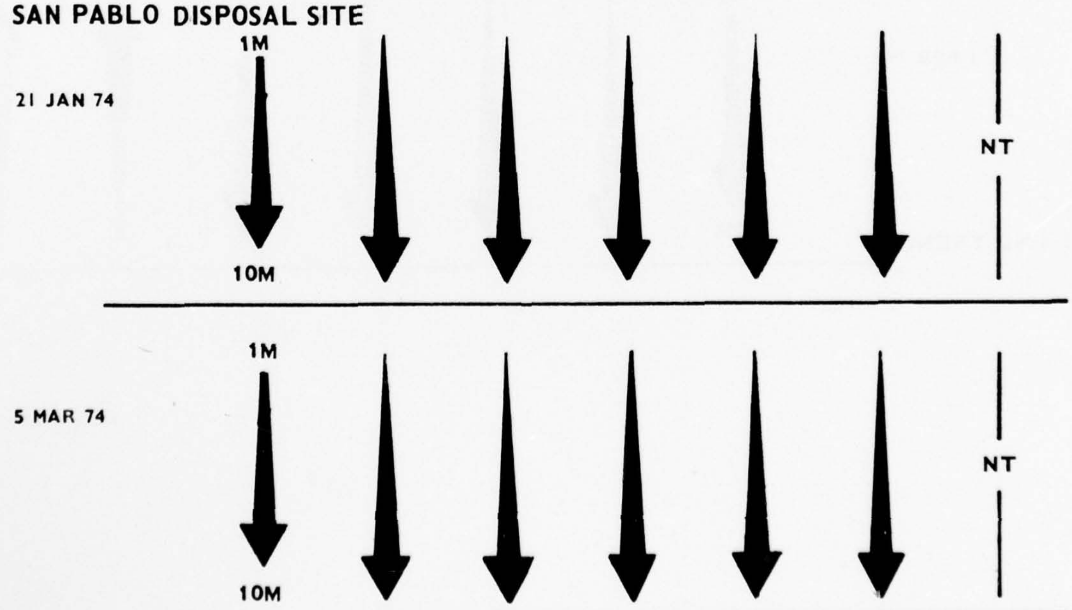


BACKGROUND LEVELS – TRENDS

PINOLE SHOAL DREDGE SITE



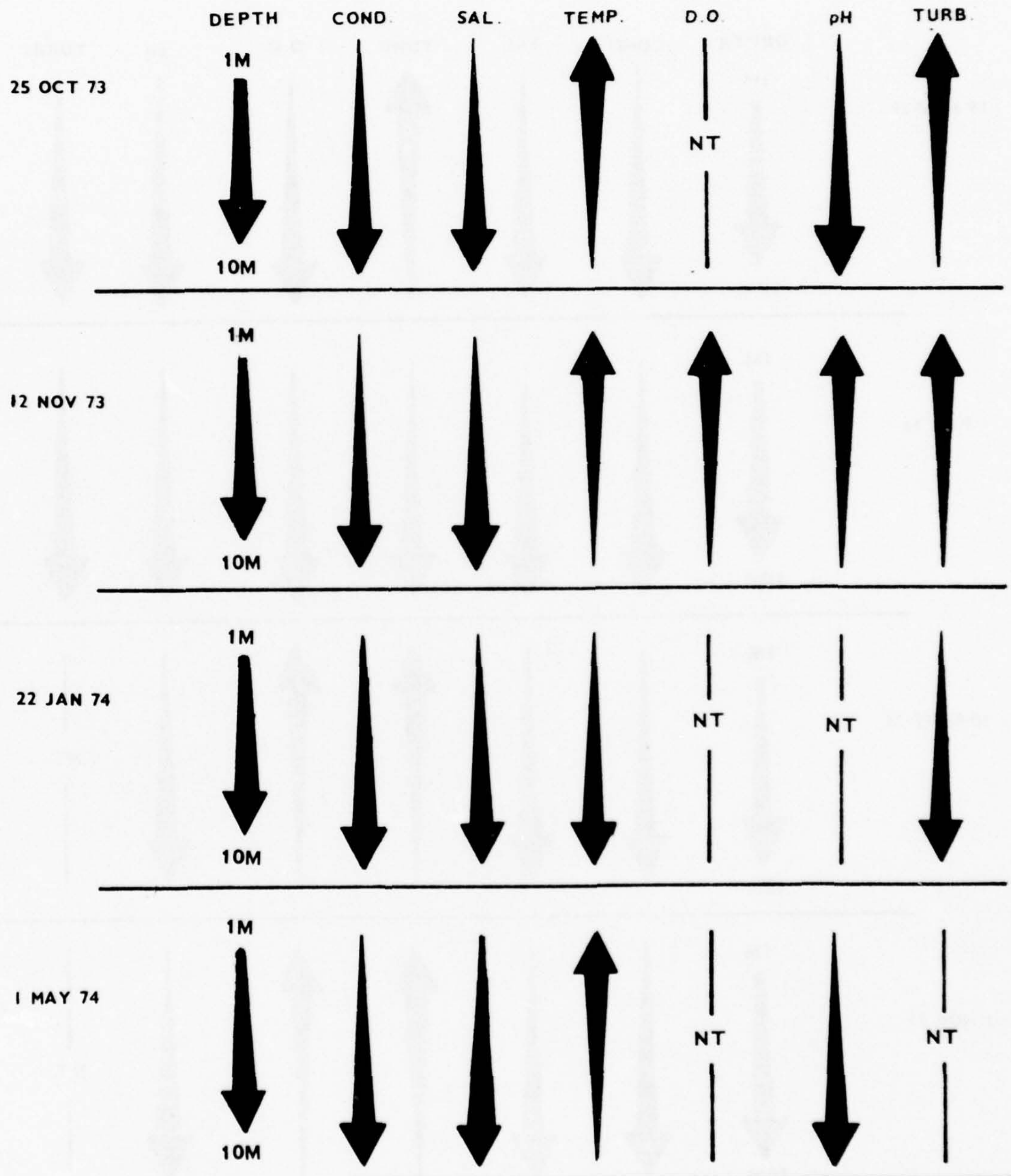
SAN PABLO DISPOSAL SITE



NT = NO TREND

BACKGROUND LEVELS – TRENDS

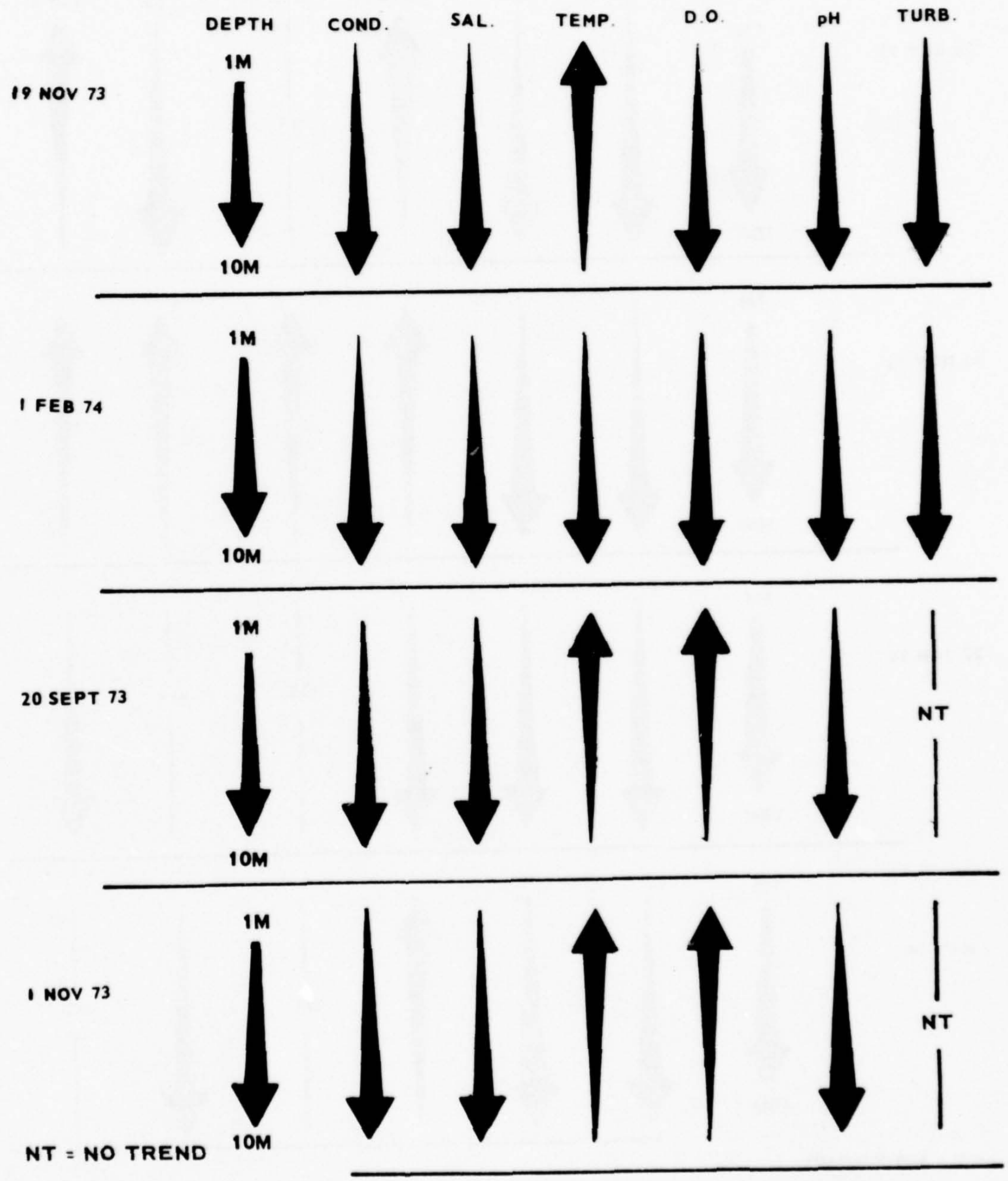
CARQUINEZ STRAITS DISPOSAL SITE



NT = NO TREND

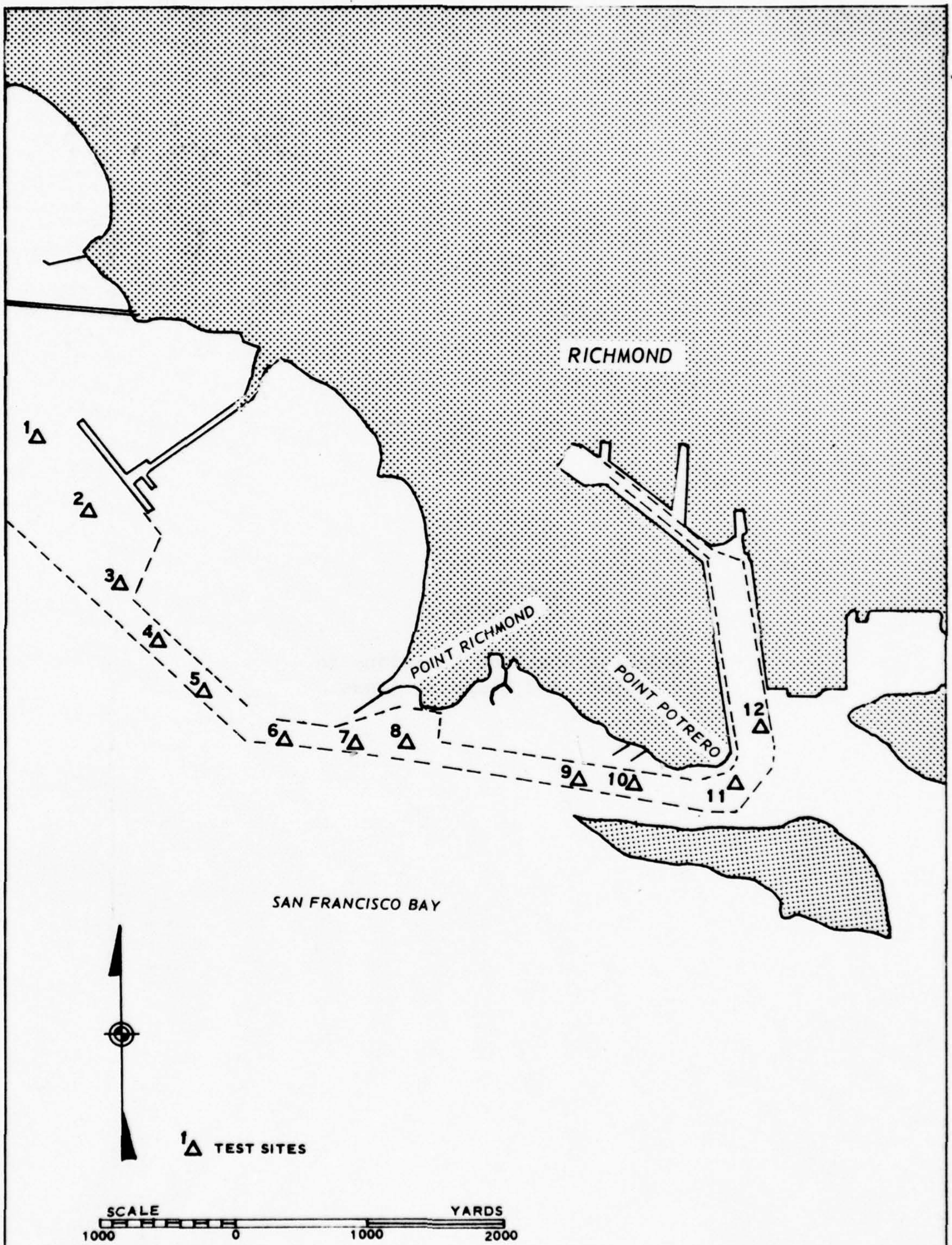
BACKGROUND LEVELS – TRENDS

ALCATRAZ DISPOSAL SITE



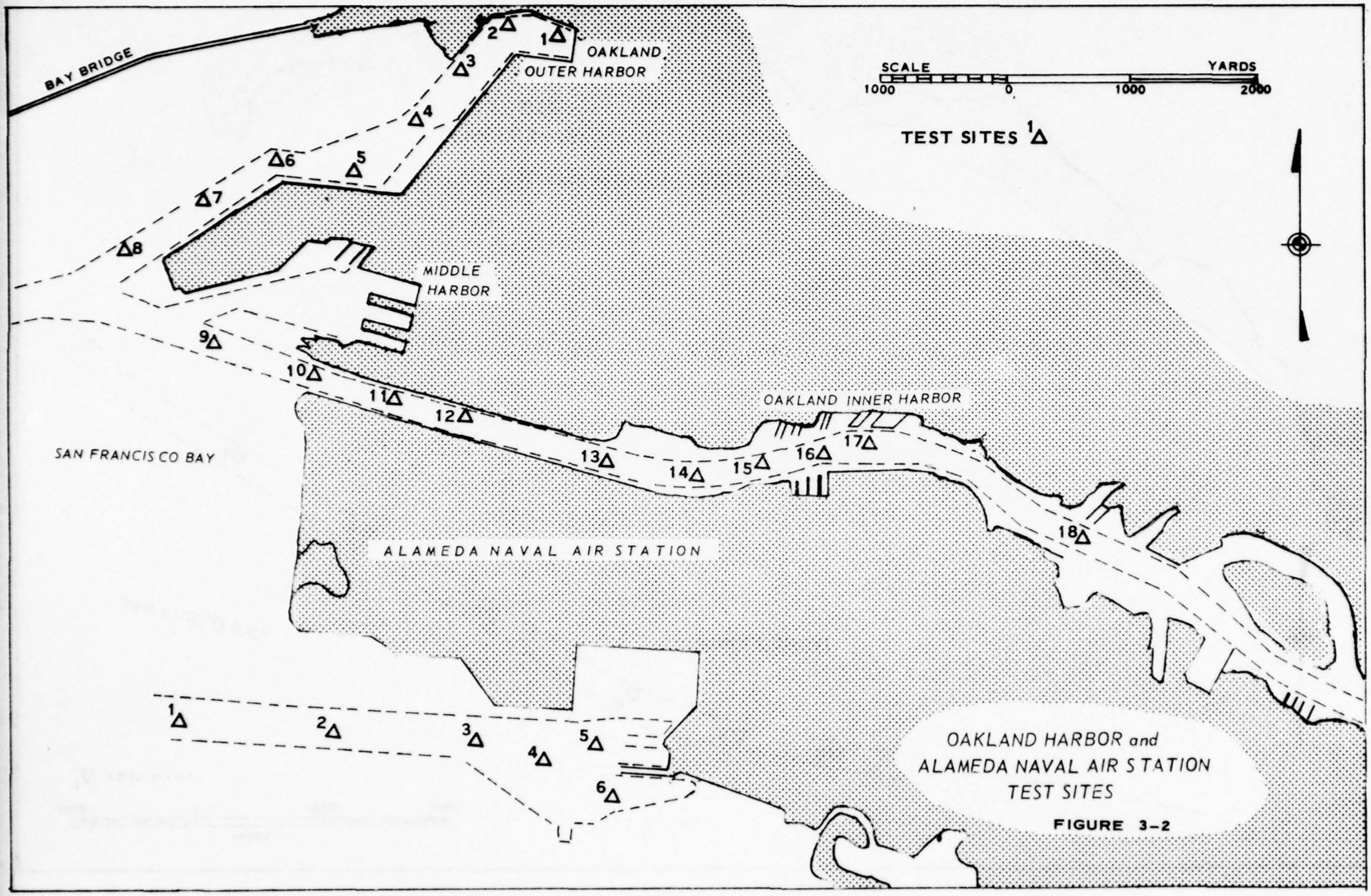
INCLOSURE 3

Sampling Stations Locations in
Project and Disposal Areas



RICHMOND HARBOR TEST SITES

FIGURE 3-1



OAKLAND HARBOR and
ALAMEDA NAVAL AIR STATION
TEST SITES

FIGURE 3-2

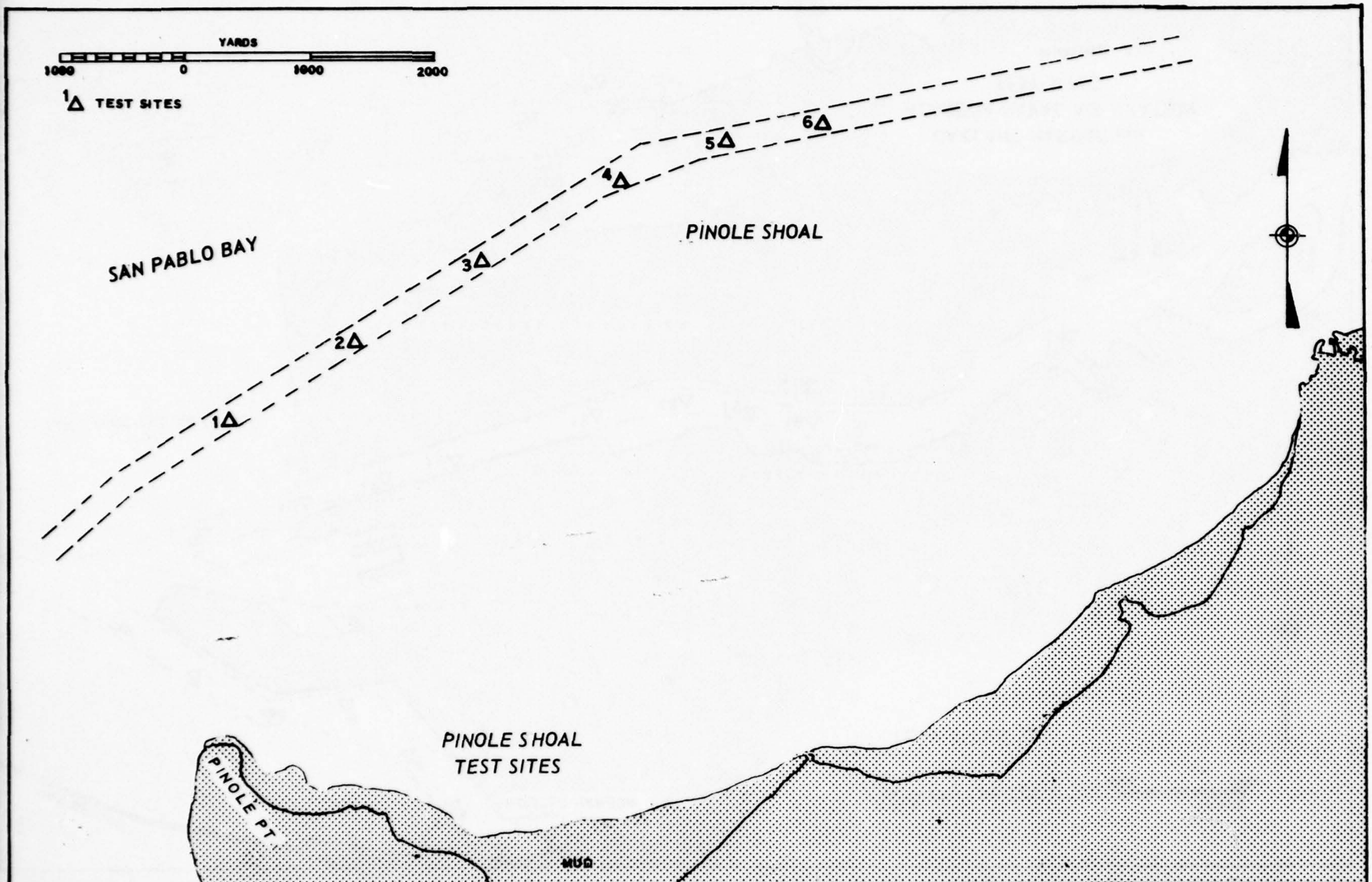
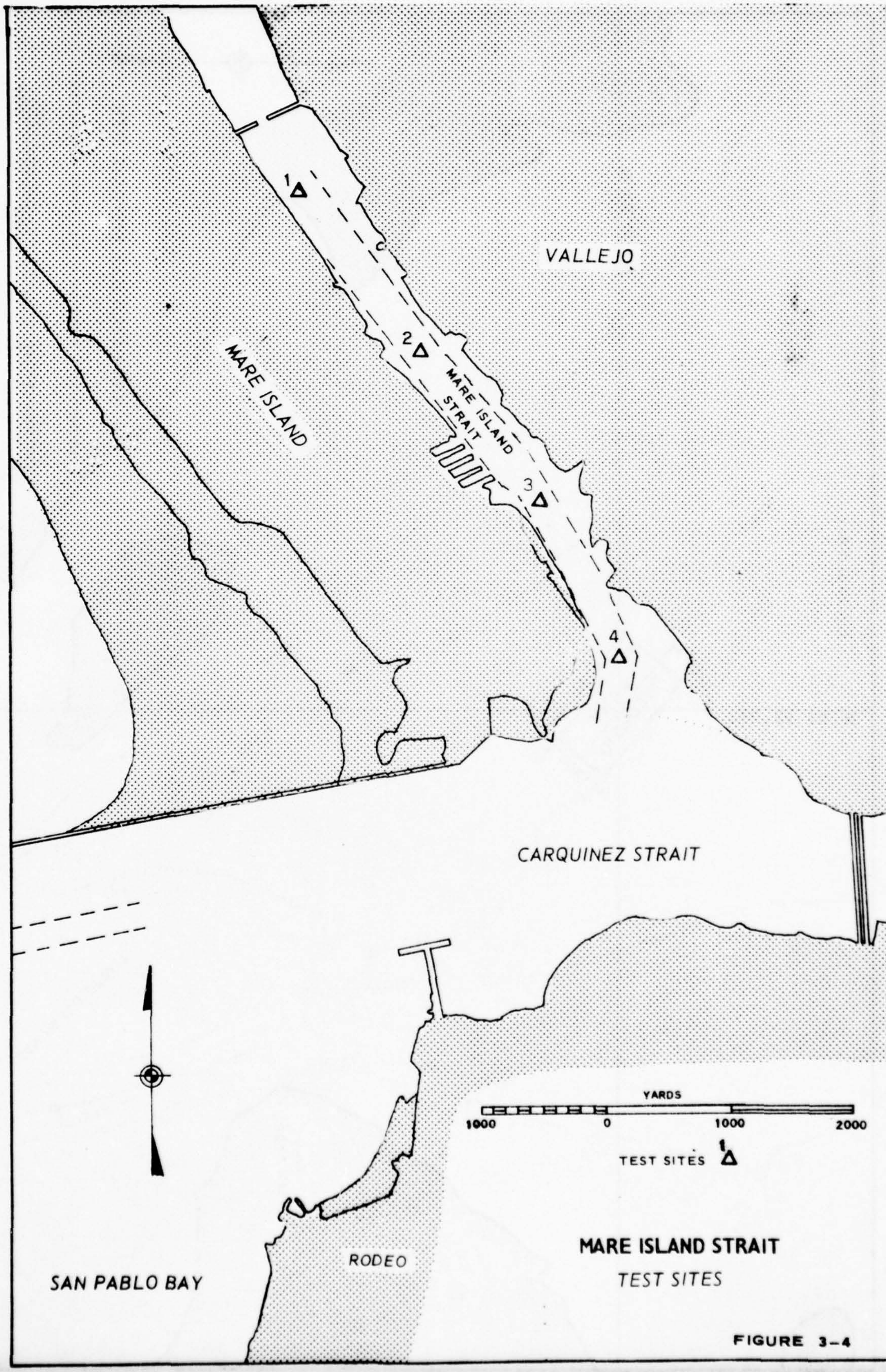
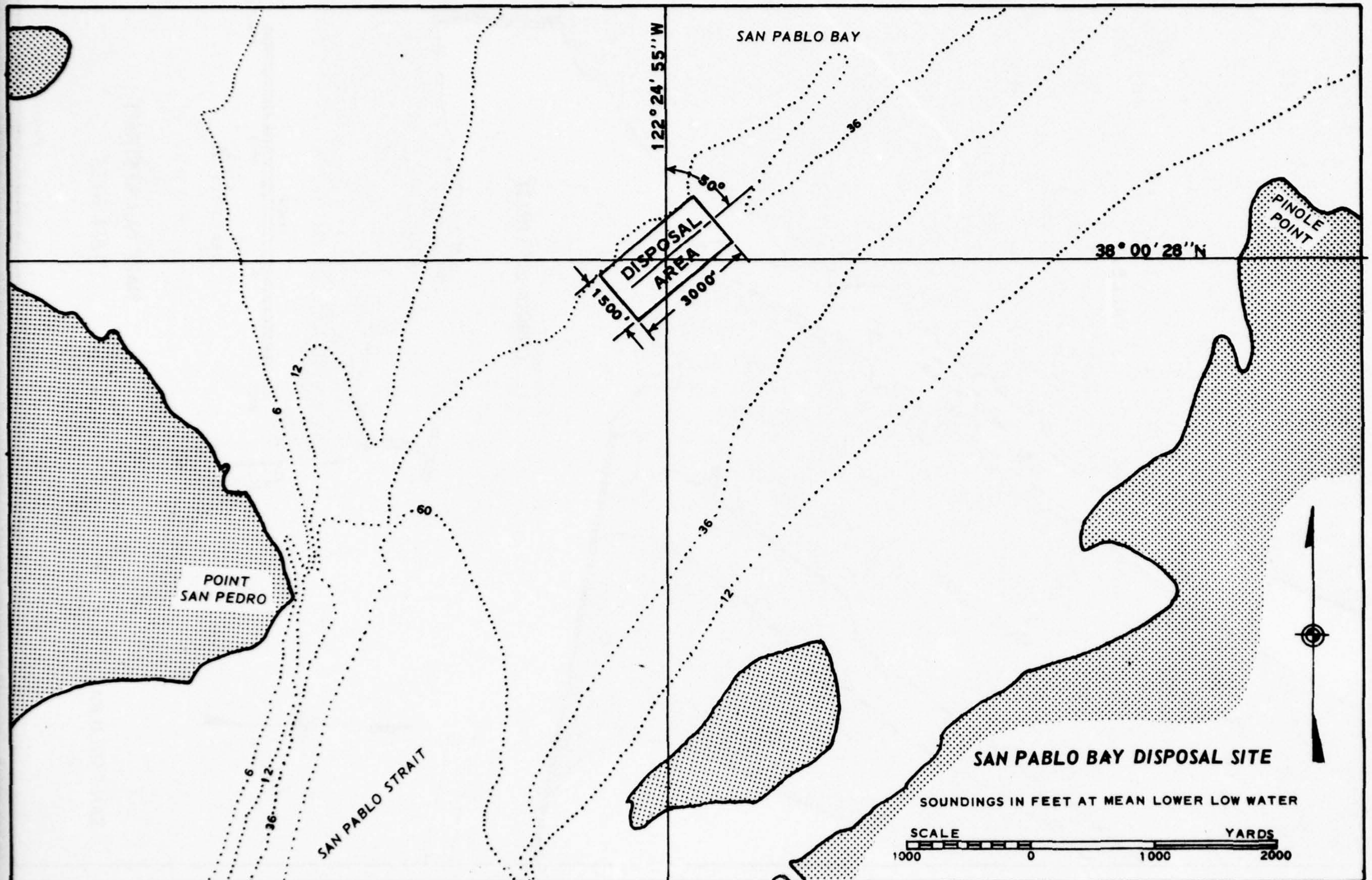

YARDS
1000
0
1000
2000
1 TEST SITES
SAN PABLO BAY
PINOLE SHOAL
1
2
3
4
5
6
PINOLE SHOAL
TEST SITES
PINOLE PT
MUD

FIGURE 3-3



MARE ISLAND STRAIT
TEST SITES

FIGURE 3-4



SAN PABLO BAY
122°24' 55''W
38°00' 28''N
DISPOSAL AREA
30°
1500'
3000'
PINOLE POINT
POINT SAN PEDRO
SAN PABLO STRAIT
36
12
6
60
SAN PABLO BAY DISPOSAL SITE
SOUNDINGS IN FEET AT MEAN LOWER LOW WATER
SCALE
YARDS
1000
0
1000
2000

FIGURE 3-5

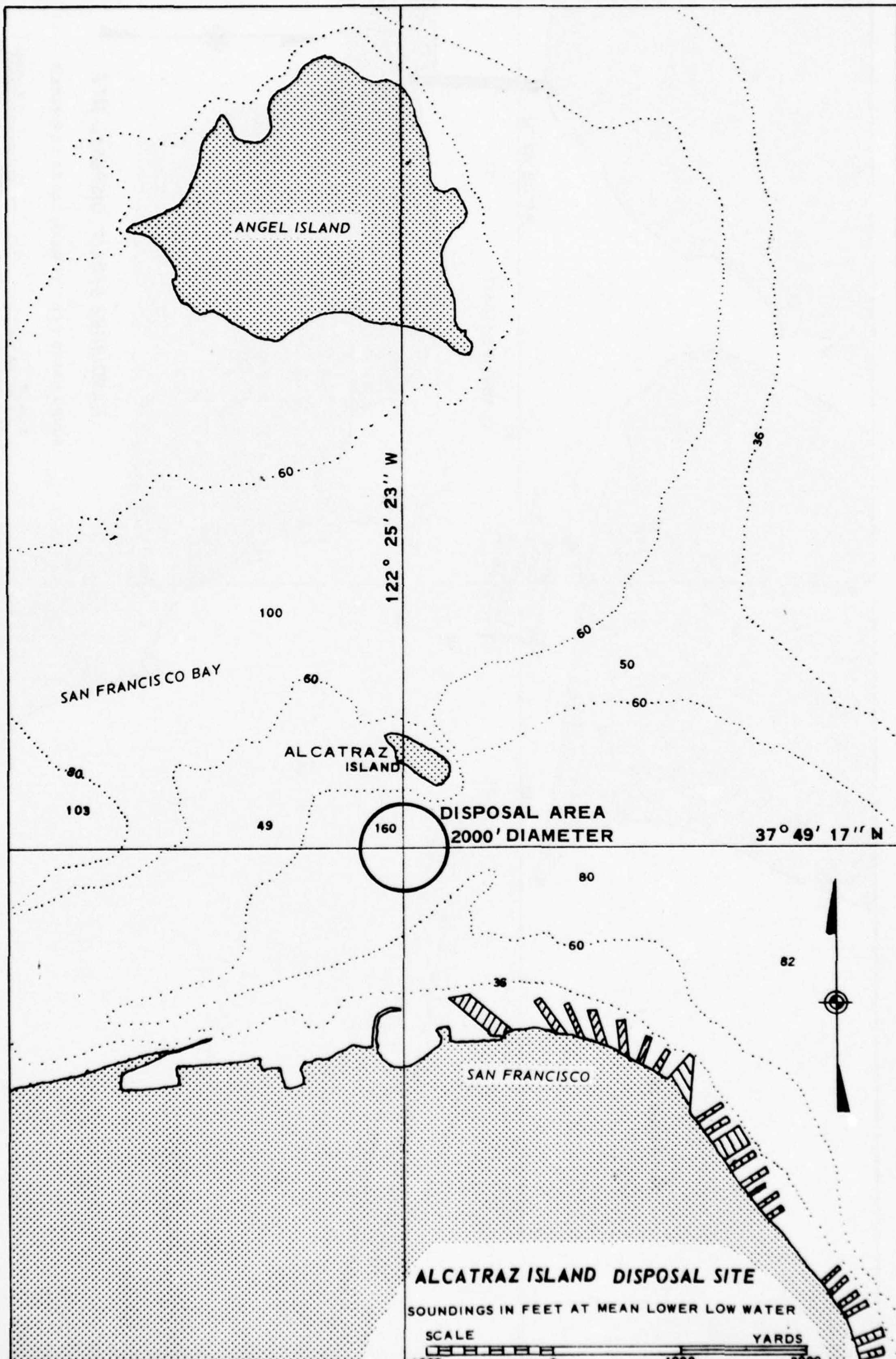

ANGEL ISLAND
122° 25' 23'' W
60
36
100
SAN FRANCISCO BAY
60
50
60
ALCATRAZ ISLAND
80
103
49
160
DISPOSAL AREA 2000' DIAMETER
37° 49' 17'' N
80
60
82
36
SAN FRANCISCO
ALCATRAZ ISLAND DISPOSAL SITE
SOUNDINGS IN FEET AT MEAN LOWER LOW WATER
SCALE
YARDS
1000 0 1000 2000

FIGURE 3-6

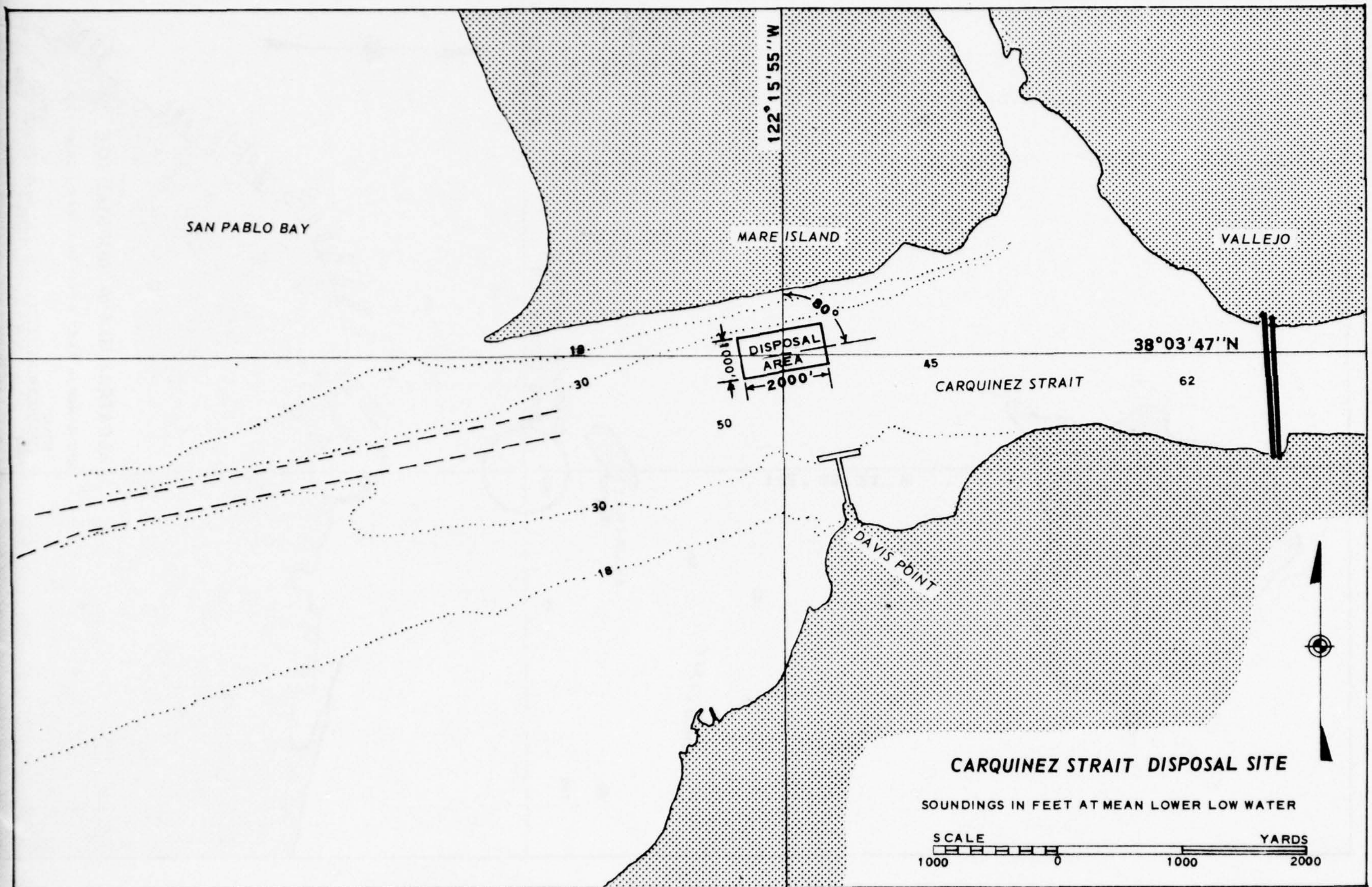

SAN PABLO BAY
MARE ISLAND
VALLEJO
122°15'55''W
38°03'47''N
80°
DISPOSAL AREA
1000'
2000'
18
30
45
50
62
CARQUINEZ STRAIT
30
18
DAVIS POINT
CARQUINEZ STRAIT DISPOSAL SITE
SOUNDINGS IN FEET AT MEAN LOWER LOW WATER
SCALE
YARDS
1000
0
1000
2000

FIGURE 3-7

INCLOSURE 4

Representative Plots of
Routine Monitoring Program

PLOTS OF ROUTINE MONITORING

During each dredging and disposal operation from late 1971 to early 1974, a standard monitoring program was followed to ascertain changes in water quality. The data obtained from these programs were plotted to aid in evaluating any observed effects. Inclosure 4-1 through 4-15 are examples of the type plots which were generated during the program. The series presented was developed from the measurements taken in Mare Island Strait Channel and at Carquinez Strait Disposal Site during 1973-1974 maintenance work. Specific observations were made from the plots as to the effect of the operations on each parameter. These observations combined with the observations obtained from dredging and disposal operations in other portions of the Bay provided the basis formulating the general conclusions, presented on page 129. The observations drawn from this series of plots are presented below. The dotted and dashed lines indicate the background conditions before the initiation of the dredging and following the completion of the project. Wide variations in background conditions could and in these cases did occur because of the time frame between measurements. The solid lines represent readings obtained during the operation.

DREDGING OBSERVATIONS

Conductivity.

a. Increased with depth if surface conductivity was greater than 4 millimhos, if less than 4 millimhos conductivity was typically homogeneous throughout water column.

b. When surface conductivity exceeded 8 millimhos, a gradient between surface and bottom water of 10 millimhos could exist. This is indicative of a stratified conditions where fresher water overlies a more saline water mass.

c. In January the conductivity was nearly homogeneous surface to bottom and along the length of the channel.

d. In May, a pronounced gradient existed from the surface to bottom of approximately 10 millimhos and was consistent along the length of the channel

e. The dredging operation did not exert a detectable influence on the background conductivity either vertically or horizontally. As the distance from the dredge increased, there was no apparent change in the conductivity.

Salinity.

a. Salinity increased with depth if the surface measurement was greater than 3 parts per thousand (ppt).

b. Above 5 ppt, salinity can increase 7 ppt in nine meters.

c. During dredging salinity aberrations did not occur astern of the dredge or at stations further downstream.

Temperature.

a. The water mass was colder in January, 10 degrees C, than it was in May, 15 degrees C.

b. Typically, temperature was vertically and horizontally uniform during January, February and March. In May the surface water was 1.5 degrees warmer than the bottom water. This is possibly a function of insolation.

c. Ebbtide may be 0.5 degrees warmer than floodtide.

d. The dredging operation did not influence temperature generally, nor as a function of distance.

pH (Hydrogen ion concentration).

a. The pH generally ranged from 7.0 to 8.5.

b. There were no significant variations with depth or along the length of the channel.

c. pH was approximately one unit lower in January than in succeeding months. This is possibly related to the introduction of fresh water via rainfall and runoff, which could drive the system from the typical slightly alkaline condition of estuarine waters towards neutrality.

d. At Station 4 during the dredging operation, pH readings of 6.0 to 6.5 were recorded. At surface a reading of 6.0 was observed at the fifty meter station. As the dredge moved upstream the pH increased to approximately 6.5. This indicates that possibly some acidic waste had been introduced into the system and the dredging operation was disturbing and removing the material. This possible caused a reduction in the pH in the water column. Because of the enormous buffering capacity of salt water, this pH value probably did not last very long before being driven back towards neutrality.

e. With the one exception at Station 4, the dredging operation did not influence the pH of the water column.

Dissolved Oxygen.

a. The dissolved oxygen concentration had background levels from 8 to 10 parts per million (ppm).

b. At Station 2, dredging caused a 3.5 ppm reduction in the oxygen level of the lower two meters of the water column (9.0 ppm to 5.5 ppm). The level returned to background concentrations by the time the second measurement was taken 100 meters downstream (a time period of approximately two minutes). The reduction was probably the result of initial demand caused by the resuspension of sediment by the draghead.

c. The 22 January background profile taken at Station 3, 100 meters downstream, was misplotted. It should read slightly greater than 8 ppm rather than slightly greater than 6 ppm as shown. During the dredging, a 0.5 ppm reduction occurred in the upper water column and a 2.5 ppm drop in the lower water column 50 meters downstream. At the 100 meter downstream position, the demand at the surface was satisfied but the reduction in the lower water column was approximately 1.5 ppm. At the 400 meter position the profile reflected background conditions throughout the water column. At the 100 meter station, another profile showed a reduction of approximately 1 ppm in the upper water column. The reduction was not apparent by the time the 400 meter position was monitored.

d. There was an approximate reduction of 2 ppm in the mid-to-lower water column at Staion 4, 50 meters downstream. The measurements had returned to the background level at the 100-meter position.

e. Of the twelve profiles run for dissolved oxygen, four showed reductions. These reductions were greatest in the lower water column but in all cases were satisfied by the time of the measurement taken at the 400 meter downstream position.

Formazine Turbidity Units (FTU).

a. Measurements both during dredging and for background levels were typically 200 FTU's or more since the instrument only records to that level as a maximum.

b. At Stations 2, 3 and 4 a definite trend of increasing FTU's with depth is apparent. During the dredging operation without overflow, the upper several meters can be at near background levels. In the lower water column, because of turbulence from the propellors and from the dragheads, readings can increase beyond the limits of the instrument. The 1 May 1974 background readings have a similar trend indicating that current velocities were sufficient to resuspend bottom material.

c. A partial clearing occurred both in the upper and lower water column as distance from the dredge increased. Typically, however, the bottom water had not cleared by the time the 400 meter position was monitored.

d. Two profiles at 50 and 100 meter positions at Station 3 and one profile at the 50 meter position at Station 4 have a "C" type profile. These profiles with higher FTU levels at the surface and bottom than in the mid-water column are indicative of the initial periods of overflow. As the duration of overflow increases, the entire water column will become loaded.

DISPOSAL OBSERVATIONS

Conductivity.

a. From January to May, surface conductivity varied from 0.5 to 14 millimhos while conductivity in the lower water column varied from 1.0 to 22 millimhos.

b. Background measurements in January and May represented the extremes during the monitoring period. In January, the mean conductivity was 1.0 millimhos and in May, it was 16 millimhos.

c. Conductivity did not show marked changes during disposal.

Salinity.

a. From January to May, surface salinity varied from 0.5 parts per thousand (ppt) to 10 ppt. The salinity of the bottom water varied from 1.0 ppt to 19 ppt.

b. Background measurements in January and May represented the extremes observed in the Strait. The mean low salinity was 1.0 ppt and the mean high was 12 ppt.

c. Measurements did not show that salinity was significantly influenced by disposal or by increasing distance from the dredge.

Temperature.

a. Temperatures typically clustered between 8 and 10 degrees centigrade for the months of January, February and March, but increased to around 14 degrees C in May.

b. Disposal operation did not seem to cause a detectable effect on temperature.

pH.

a. The pH values clustered around 8. This is typical for waters influenced by oceanic water masses.

b. During disposal, there was no detectable aberration from this oceanic mean nor was there a detectable change due to increasing distance from the operation.

Dissolved Oxygen.

a. Dissolved oxygen concentrations never dropped below 8 parts per million (ppm).

b. At the fifty meter downstream station, there was a 1.5 ppm reduction at the surface and 1.0 ppm reduction in the mid water column.

c. By the hundred meter measurement, the surface decrease (1.5 ppm) at the 50 meter station had been partially satisfied and was only a 0.5 ppm reduction. In the lower water column there were two cases of reductions of 1.0 ppm each.

d. At the 400 meter station, a residual decrease of approximately 1 ppm existed in the mid to lower water column in one case.

Turbidity (as percent transmission).

a. The entire water column could be loaded to the point which exceeded the measurement capacity of the instrument. This occurred during both disposal operations and when background measurements were taken.

b. In all but one case turbidity at the 10 meter depth was less than eight percent transmittance.

c. As distance from the vessel increased, there was usually a steady increase in upper water column clarity.

d. At the 400 meter station all but one operation showed some partial clearing of the surface waters.

Formazine Turbidity Units (FTU).

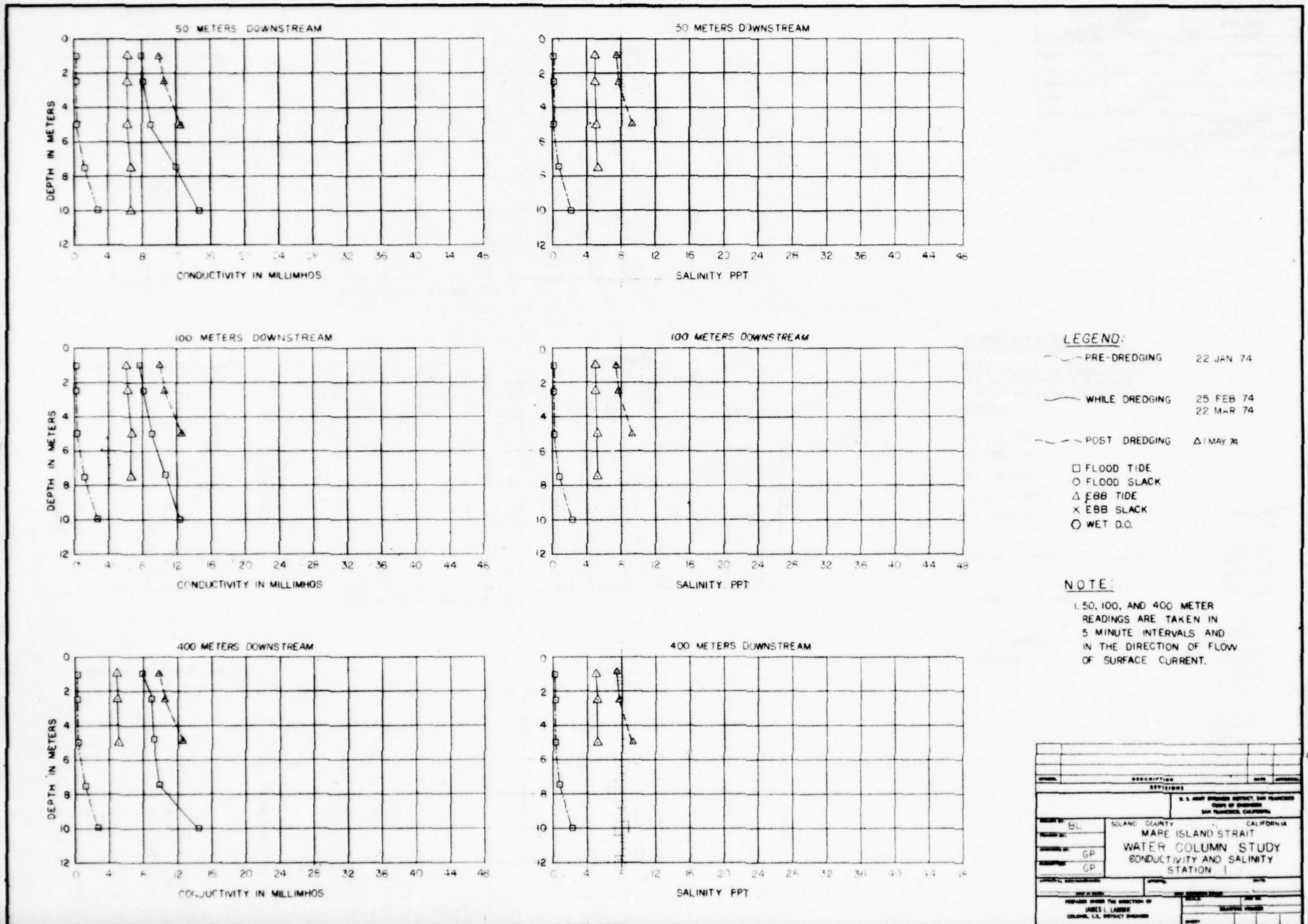
a. Measurements for both background and during disposal showed readings of greater than 200 FTU's which equals 200-300 mg/l suspended solids.

b. At the 50 meter station, there are several plots which have the "C" configuration. This configuration is indicative of the surface loading caused by propellor wash and by predisposal overflow. It also indicates the bottom loading caused by the dredge material impacting on the bottom. Before settling of surface particles and drifting of particles near the bottom, the center portion of the water column shows little influence.

c. In general as distance from the vessel increased the upper water column cleared proportionally.

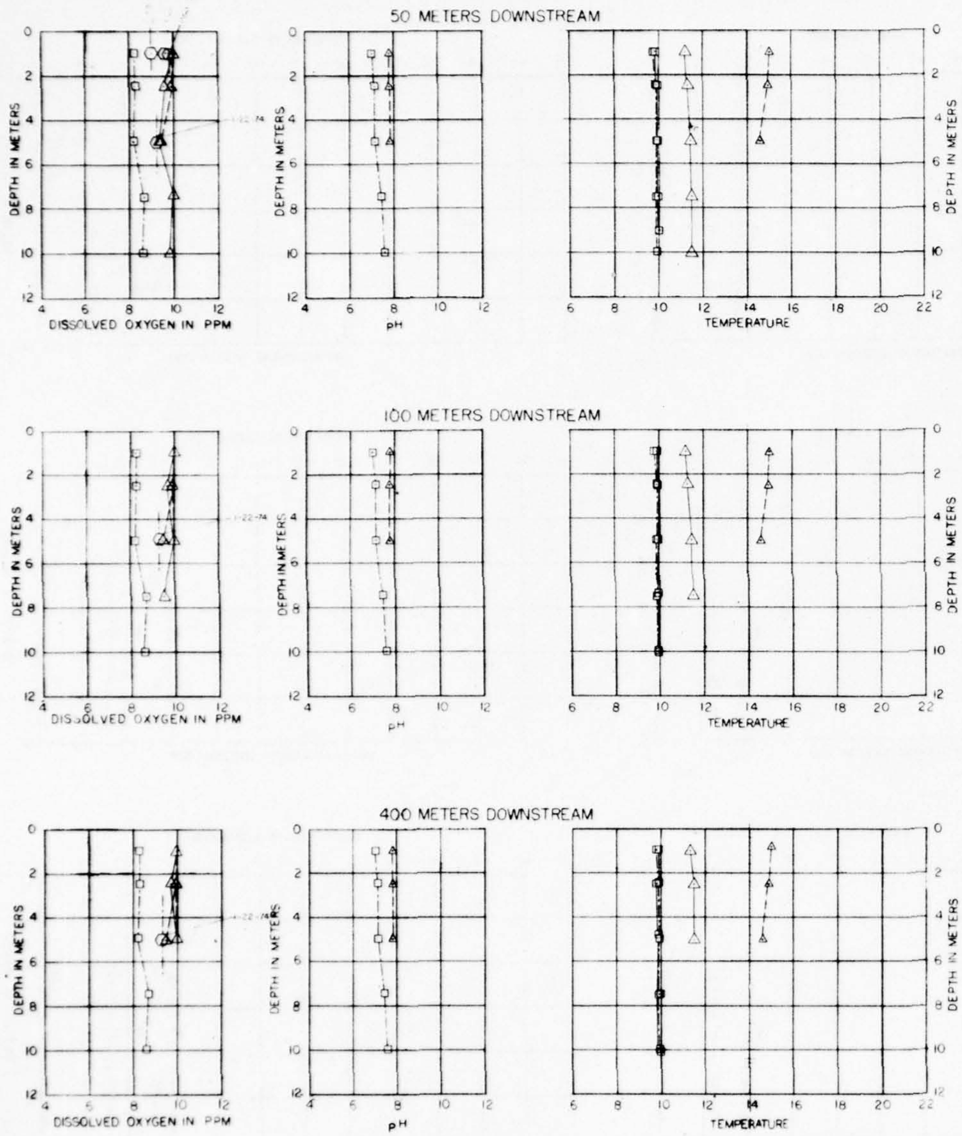
d. At the 100 meter station, the water below the five meter depth was typically above the 200 FTU level.

e. At the 400 meter station, there was a partial clearing down to the seven and one-half meter depth.



50 METERS DOWNSTREAM
100 METERS DOWNSTREAM
400 METERS DOWNSTREAM
DEPTH IN METERS
CONDUCTIVITY IN MILLIMHOS
SALINITY PPT
LEGEND:
PRE-DREDGING 22 JAN 74
WHILE DREDGING 25 FEB 74
22 MAR 74
POST DREDGING △ 1 MAY 74
□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
○ WET D.O.
NOTE:
1. 50, 100, AND 400 METER READINGS ARE TAKEN IN 5 MINUTE INTERVALS AND IN THE DIRECTION OF FLOW OF SURFACE CURRENT.
REVISIONS
SOLANO COUNTY CALIFORNIA
MARE ISLAND STRAIT
WATER COLUMN STUDY
CONDUCTIVITY AND SALINITY
STATION 1

FIGURE 4-1



LEGEND

- PRE-DREDGING 22 JAN 74
- WHILE DREDGING 25 FEB 74, 22 MAR 74
- POST DREDGING 21 MAY 74

- □ FLOOD TIDE
- ○ FLOOD SLACK
- △ EBB TIDE
- ✕ EBB SLACK
- ○ WET D.O.

NOTES

1. 50, 100 AND 400 METER READINGS ARE TAKEN AT 5 MINUTE INTERVALS IN THE DIRECTION OF SURFACE CURRENT FLOW.
2. DISSOLVED OXYGEN IS MEASURED IN PARTS PER MILLION

SYMBOL	DESCRIPTION	DATE	APPROVAL
	REVISIONS		

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SAN FRANCISCO, CALIFORNIA

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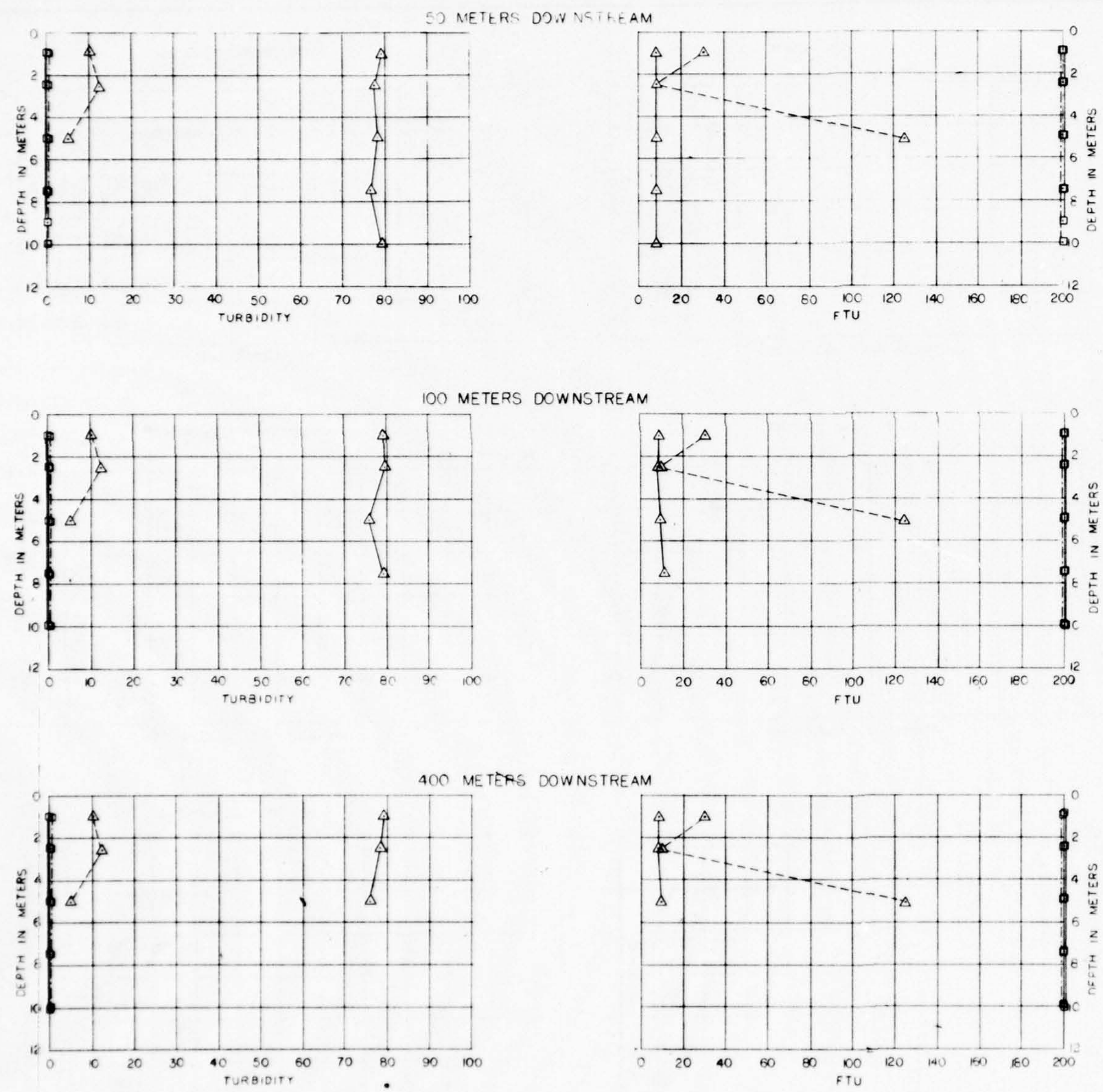
SOLANO COUNTY CALIFORNIA
MARE ISLAND STRAIT
WATER COLUMN STUDY
DISSOLVED OXYGEN pH TEMPERATURE
STATION 1

PREPARED UNDER THE DIRECTION OF
JAMES L. LAMMIE
COLONEL, C.E. DISTRICT ENGINEER

FIGURE 4 -2



PRE DREDGING 22 JAN 74

WHILE DREDGING 25 FEB 74, 22 MAR 74

POST DREDGING △ 1 MAY 74

□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
○ WET DO

NOTES:

1. 50, 100, AND 400 METER READINGS ARE TAKEN IN 5 MINUTE INTERVALS AND IN THE DIRECTION OF FLOW OF SURFACE CURRENTS.
2. TURBIDITY MEASURED IN PERCENT LIGHT TRANSMITTED THROUGH A TEN CENTIMETER WATER COLUMN.

SYMBOL	DESCRIPTION	DATE	APPROVAL
	REVISIONS		

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SAN FRANCISCO, CALIFORNIA

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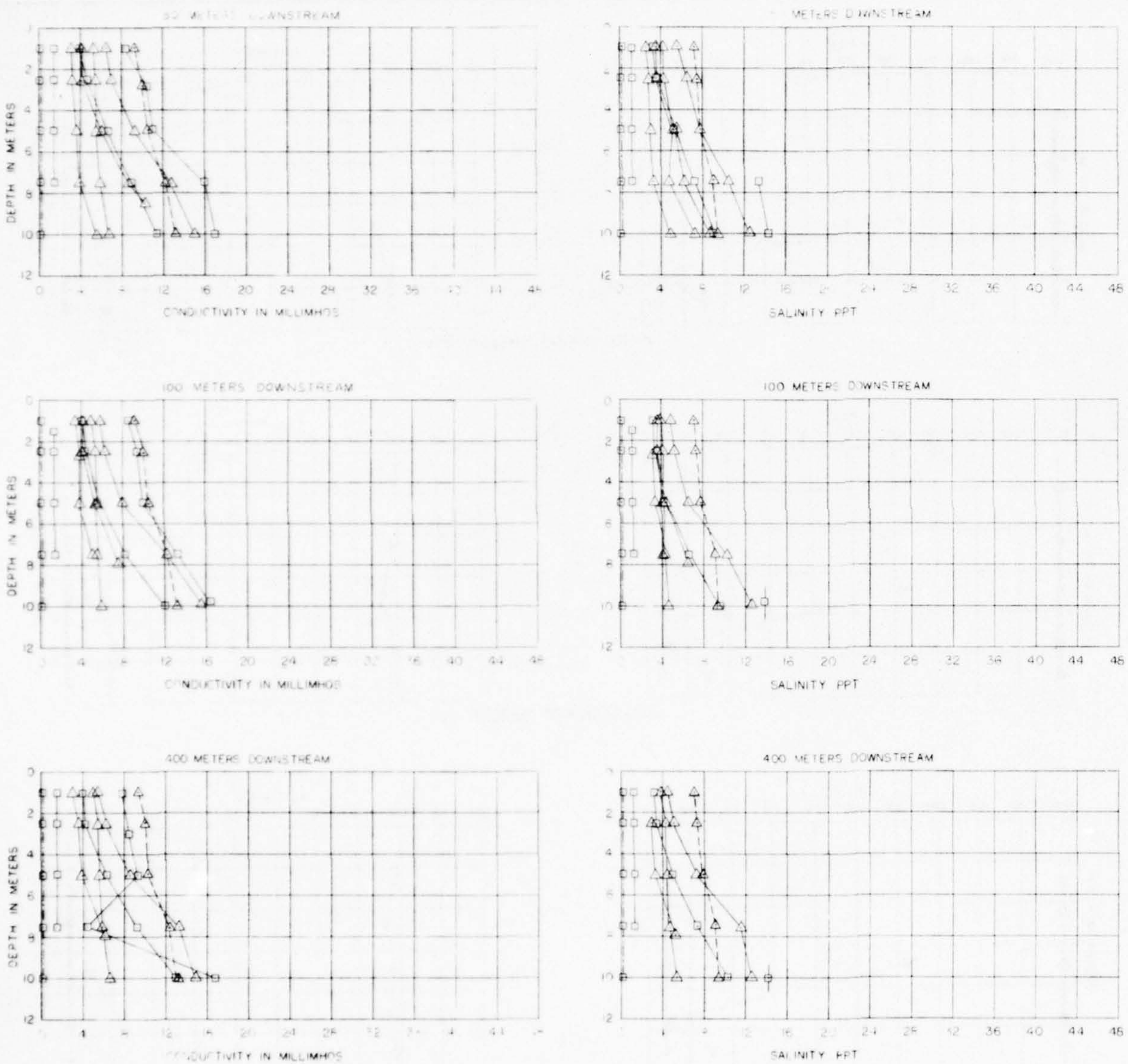
SUBMITTED: GP

SOLANO COUNTY CALIFORNIA
MARE ISLAND STRAIT
WATER COLUMN STUDY
TURBIDITY AND FTU
STATION 1

PREPARED UNDER THE DIRECTION OF
JAMES L. LAMMIE
COLONEL, C.E., DISTRICT ENGINEER

FIGURE 4 -3



LEGEND:

PRE-DREDGING 22 JAN 74

WHILE DREDGING 13,25 FEB 74 5,11,22,25 MAR 74

POST DREDGING 1 MAY 74

□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
◯ WET D.O.

NOTE:

1. 50, 100, AND 400 METER READINGS ARE TAKEN IN 5 MINUTE INTERVALS AND IN THE DIRECTION OF FLOW OF SURFACE CURRENT.

REVISIONS

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SOLANO COUNTY CALIFORNIA

MARE ISLAND STRAIT

WATER COLUMN STUDY

CONDUCTIVITY AND SALINITY

STATION 2

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SUBMITTED: GP

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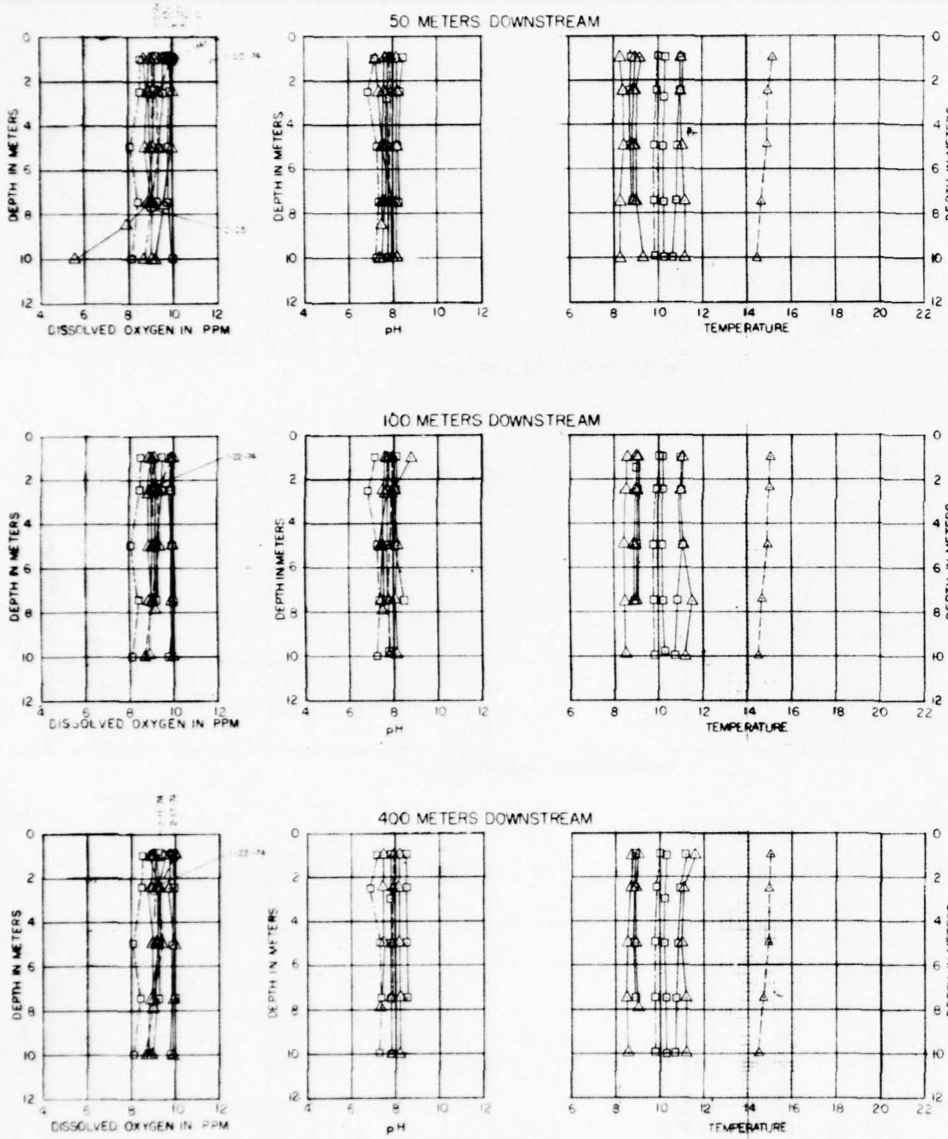
COLONEL, C.E. DISTRICT ENGINEER

FIGURE 4-4



LEGEND:

PRE-DREDGING 22 JAN 74

WHILE DREDGING 13,25 FEB 74
5,11,22,25 MAR 74

POST DREDGING △ 1 MAY 74

□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
○ WET D.O.

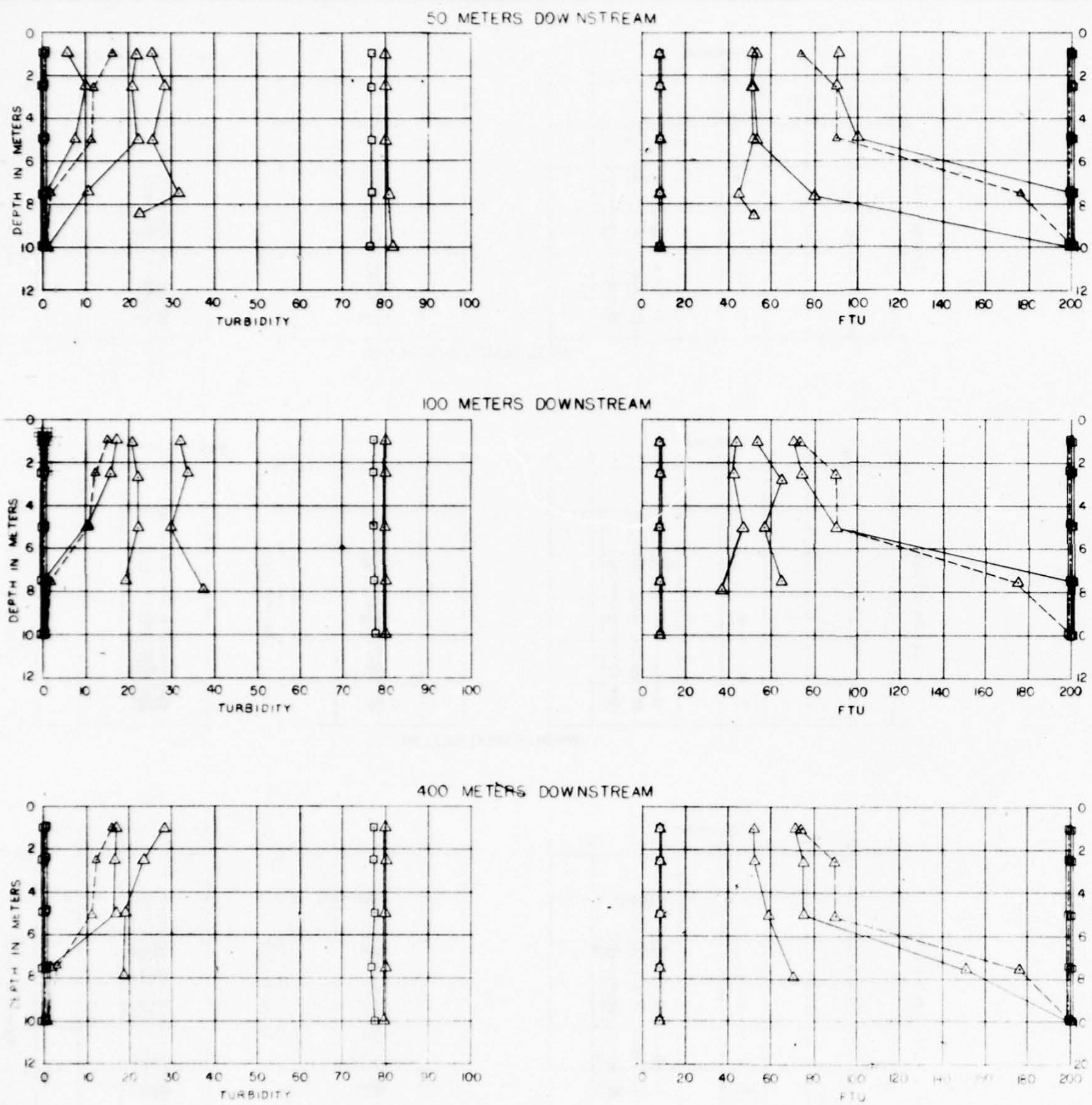
NOTES

1. 50, 100 AND 400 METER READINGS ARE TAKEN AT 5 MINUTE INTERVALS IN THE DIRECTION OF SURFACE CURRENT FLOW.

2. DISSOLVED OXYGEN IS MEASURED IN PARTS PER MILLION

SOLANO COUNTY CALIFORNIA
MARE ISLAND STRAIT
WATER COLUMN STUDY
DISSOLVED OXYGEN pH TEMPERATURE
STATION 2

FIGURE 4-5



PRE DREDGING 22 JAN 74

WHILE DREDGING 13,25 FEB 74
5,11,22,25 MAR 74

POST DREDGING △ 1 MAY 74

□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
○ WET DO

NOTES
1. 50, 100, AND 400 METER READINGS ARE TAKEN IN 5 MINUTE INTERVALS AND IN THE DIRECTION OF FLOW OF SURFACE CURRENTS
2. TURBIDITY MEASURED IN PERCENT LIGHT TRANSMITTED THROUGH A TEN CENTIMETER WATER COLUMN.

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MARE ISLAND STRAIT
WATER COLUMN STUDY
TURBIDITY AND FTU
STATION 2

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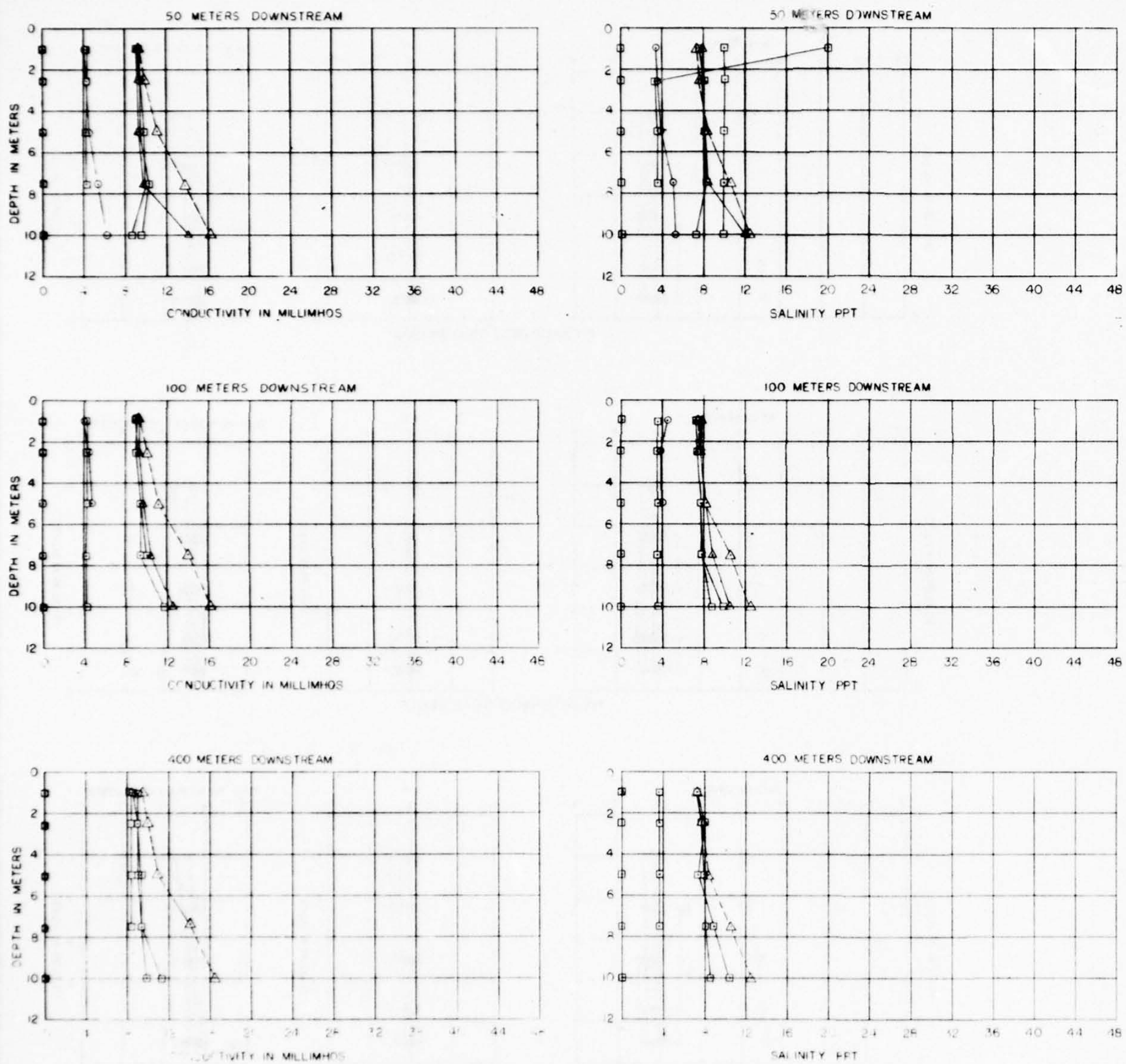
COLONEL, C.E., DISTRICT ENGINEER

FIGURE 4-6



LEGEND:

- PRE-DREDGING □ 22 JAN 74
- WHILE DREDGING ○ 13 FEB 74, □ 26 FEB 74, △ 27 FEB 74, □ 27 FEB 74, ○ 11 MAR 74, □ 11 MAR 74, △ 12 MAR 74, □ 27 MAR 74
- POST DREDGING △ 1 MAY 74

□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
○ WET D.O.

NOTE:

1. 50, 100, AND 400 METER READINGS ARE TAKEN IN 5 MINUTE INTERVALS AND IN THE DIRECTION OF FLOW OF SURFACE CURRENT.

U.S. ARMY ENGINEER DISTRICT SAN FRANCISCO
CORPS OF ENGINEERS
SAN FRANCISCO, CALIFORNIA

SOLANO COUNTY CALIFORNIA
MARE ISLAND STRAIT
WATER COLUMN STUDY
CONDUCTIVITY AND SALINITY
STATION 3

PREPARED UNDER THE DIRECTION OF
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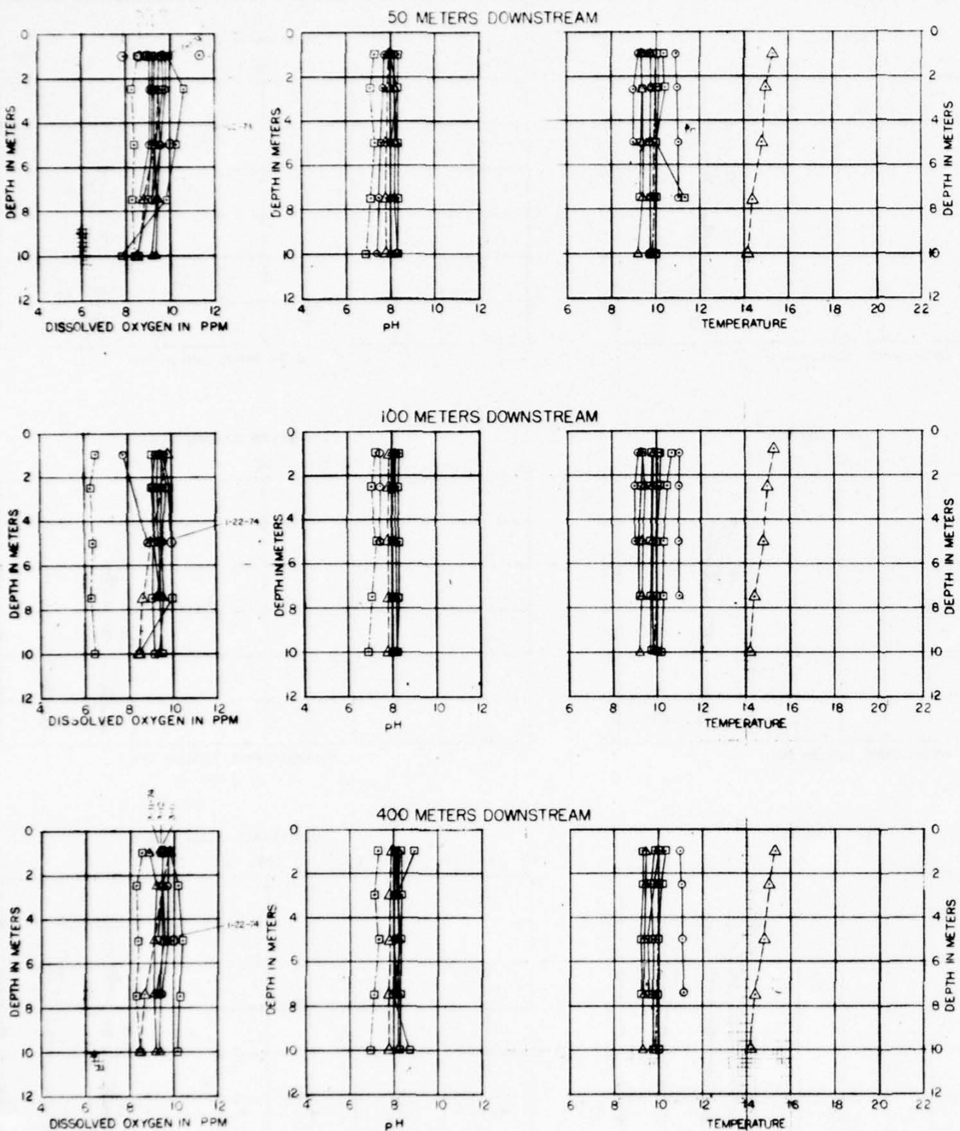
COLONEL, C.E., DISTRICT ENGINEER

FIGURE 4-7



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LEGEND:

PRE-DREDGING — 22 JAN 74

WHILE DREDGING — 13 FEB 74, 26 FEB 74, 27 FEB 74, 27 FEB 74, 11 MAR 74, 11 MAR 74, 12 MAR 74, 27 MAR 74

POST DREDGING — 1 MAY 74

□ FLOOD TIDE

○ FLOOD SLACK

△ EBB TIDE

× EBB SLACK

○ WET D.O.

NOTES

1. 50, 100 AND 400 METER READINGS ARE TAKEN AT 5 MINUTE INTERVALS IN THE DIRECTION OF SURFACE CURRENT FLOW.

2. DISSOLVED OXYGEN IS MEASURED IN PARTS PER MILLION

DESCRIPTION	REVISIONS
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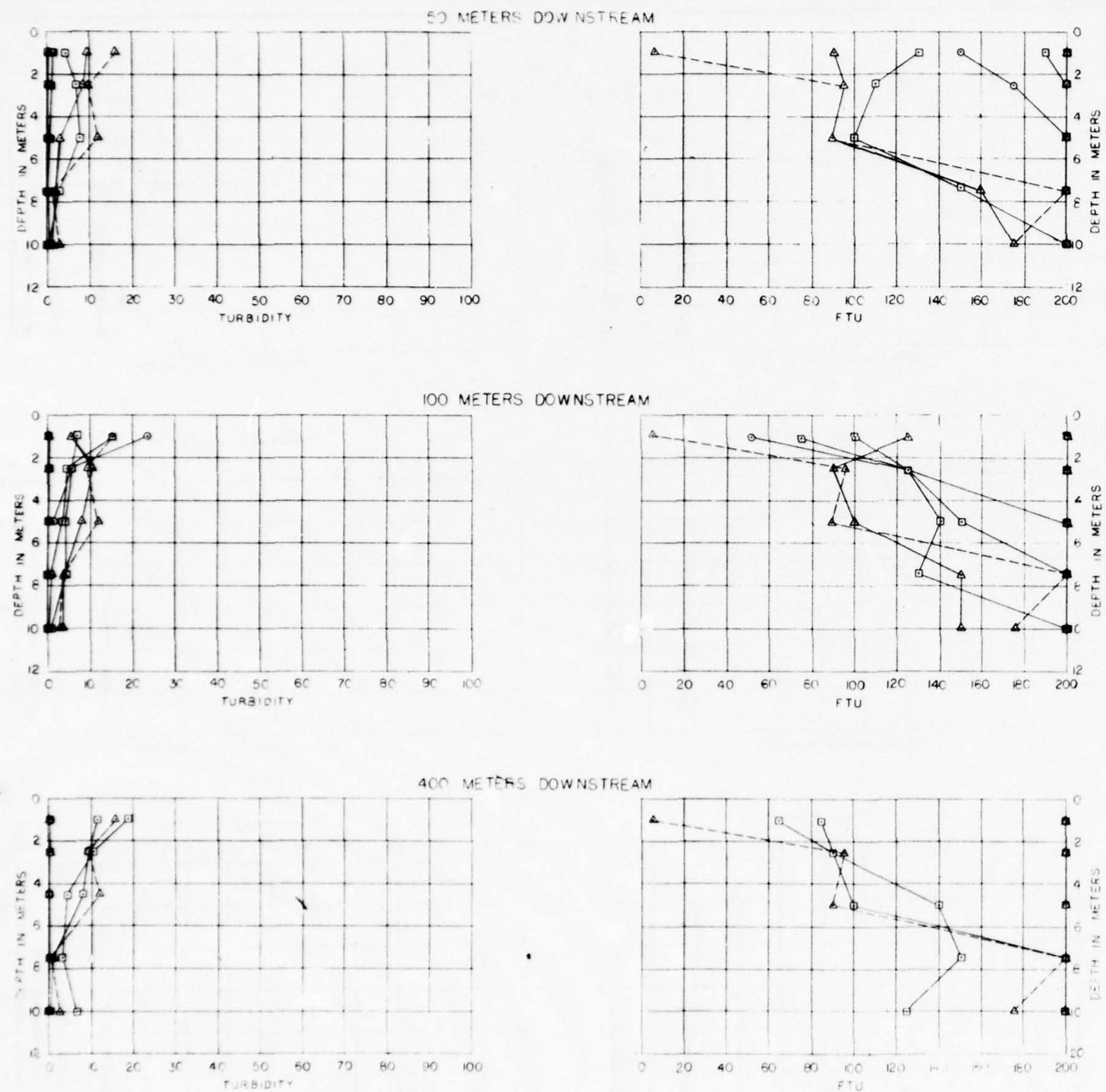
GP	MARE ISLAND STRAIT WATER COLUMN STUDY
GP	DISSOLVED OXYGEN pH TEMPERATURE STATION 3
PREPARED UNDER THE DIRECTION OF JAMES L. LAMMIE COLONEL, C.E., DISTRICT ENGINEER	

FIGURE 4-8



PRE DREDGING □ 22 JAN 74

WHILE DREDGING ○ 13 FEB 74, 26 FEB 74, 27 FEB 74, 27 FEB 74, 11 MAR 74, 11 MAR 74, 12 MAR 74

POST DREDGING △ 1 MAY 74

□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
○ WET DO

NOTES:
1. 50, 100, AND 400 METER READINGS ARE TAKEN IN 5 MINUTE INTERVALS AND IN THE DIRECTION OF FLOW OF SURFACE CURRENTS
2. TURBIDITY MEASURED IN PERCENT LIGHT TRANSMITTED THROUGH A TEN CENTIMETER WATER COLUMN.

SYMBOL	DESCRIPTION	DATE	APPROVAL
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SAN FRANCISCO, CALIFORNIA

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SOLANO COUNTY CALIFORNIA
MARE ISLAND STRAIT
WATER COLUMN STUDY
TURBIDITY AND FTU
STATION 1

APPROVAL RECOMMENDED: APPROVED: DATE:

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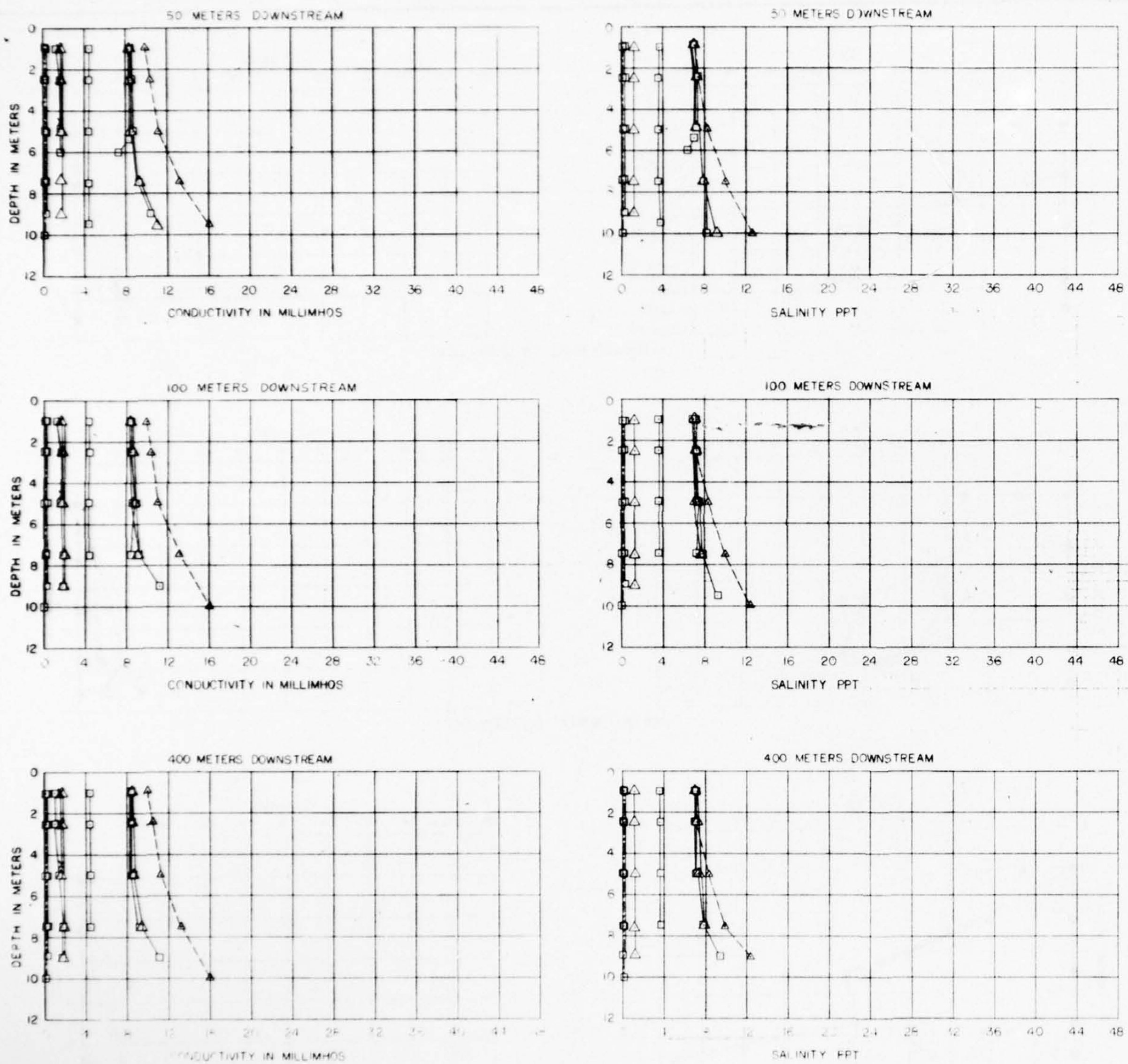
JAMES L. LAMMIE
COLONEL, C.E. DISTRICT ENGINEER

SCALE: JOB No.: DRAWING NUMBER
SHEET

FIGURE 4 – 9



LEGEND:

- PRE-DREDGING 22 JAN 74
- WHILE DREDGING 26,27 FEB 74; 8,11,12,27 MAR 74
- POST DREDGING △ 1 MAY 74

□ FLOOD TIDE
□ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
○ WET D.O.

NOTE:

1. 50, 100, AND 400 METER READINGS ARE TAKEN IN 5 MINUTE INTERVALS AND IN THE DIRECTION OF FLOW OF SURFACE CURRENT.

SYMBOL	DESCRIPTION	DATE	APPROVAL
	REVISIONS		

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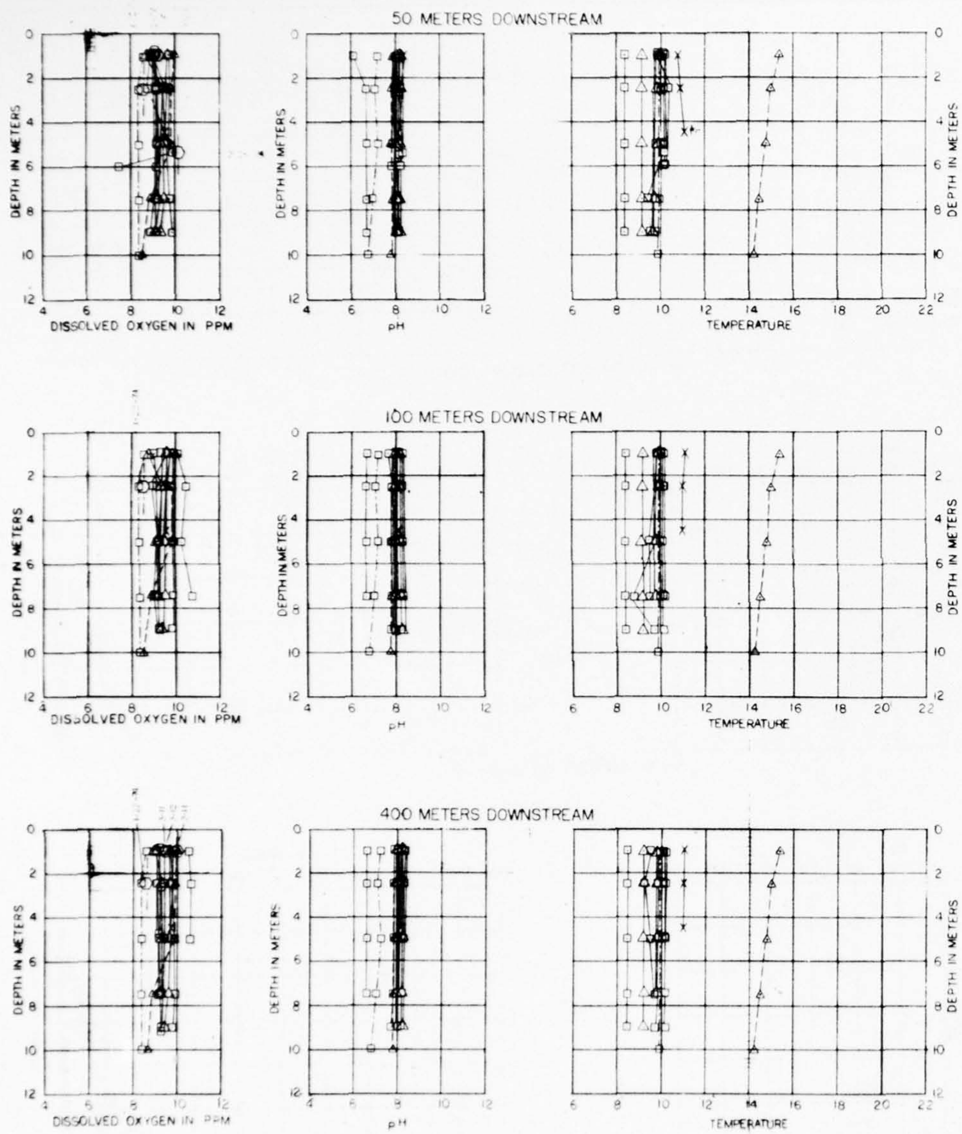
SOLANO COUNTY CALIFORNIA
MARE ISLAND STRAIT
WATER COLUMN STUDY
CONDUCTIVITY AND SALINITY
STATION 4

PREPARED UNDER THE DIRECTION OF
JAMES L. LAMMIE
COLONEL, C.E., DISTRICT ENGINEER

FIGURE 4-10



LEGEND:

PRE-DREDGING 22 JAN 74

WHILE DREDGING 26,27 FEB 74; 8,11,12,27 MAR 74

POST DREDGING △ 1 MAY 74

□ FLOOD TIDE

○ FLOOD SLACK

△ EBB TIDE

× EBB SLACK

○ WET D.O.

NOTES

1. 50, 100 AND 400 METER READINGS ARE TAKEN AT 5 MINUTE INTERVALS IN THE DIRECTION OF SURFACE CURRENT FLOW.

2. DISSOLVED OXYGEN IS MEASURED IN PARTS PER MILLION

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SAN FRANCISCO, CALIFORNIA

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SOLANO COUNTY CALIFORNIA
MARE ISLAND STRAIT
WATER COLUMN STUDY
DISSOLVED OXYGEN pH TEMPERATURE
STATION 4

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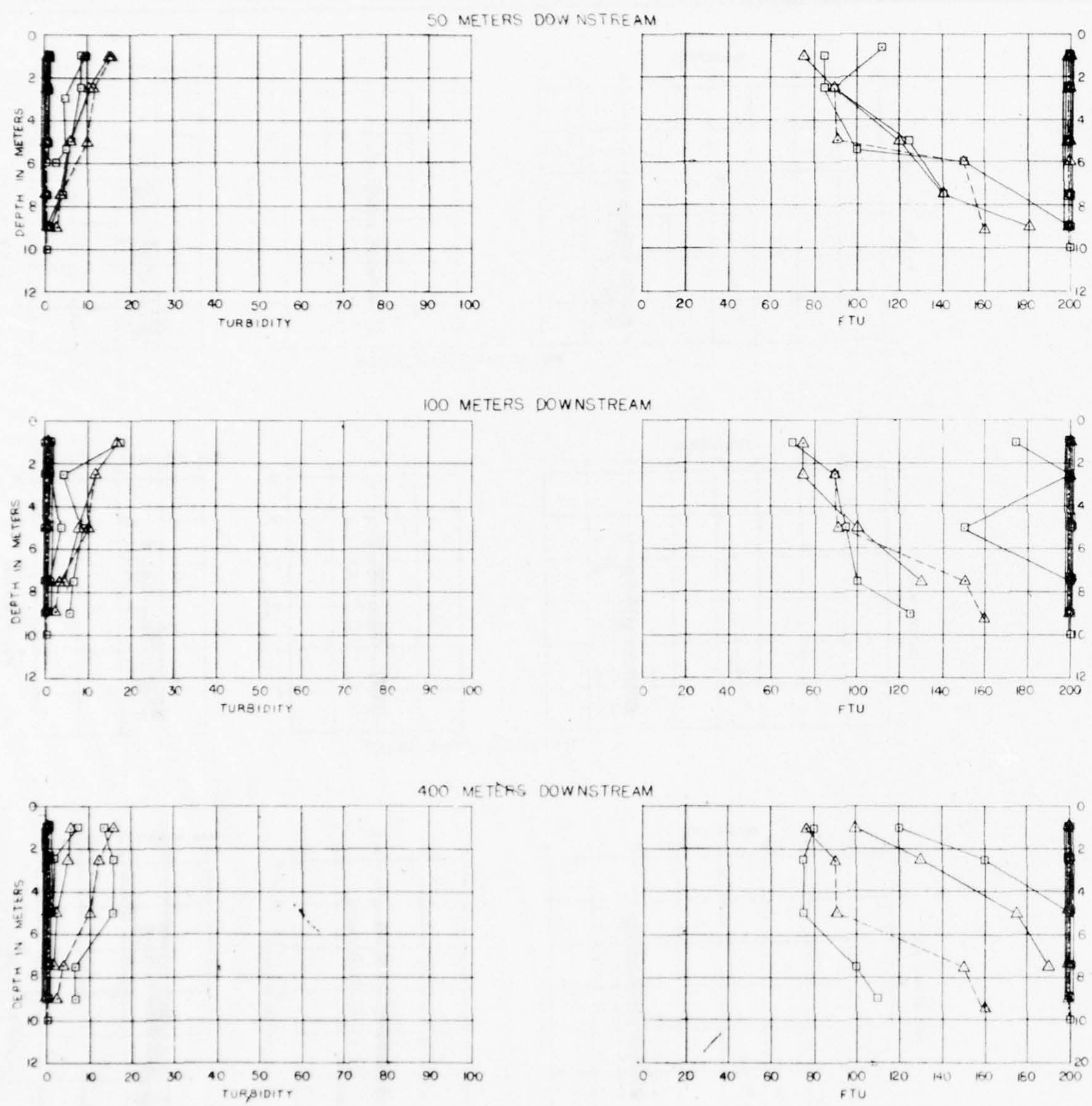
COLONEL, C.E. DISTRICT ENGINEER

FIGURE 4-11



PRE DREDGING 22 JAN 74

WHILE DREDGING 26,27 FEB 74
8,11,12,27 MAR 74

POST DREDGING △ 1 MAY 74

□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
○ WET D.O.

NOTES:

1. 50, 100, AND 400 METER READINGS ARE TAKEN IN 5 MINUTE INTERVALS AND IN THE DIRECTION OF FLOW OF SURFACE CURRENTS
2. TURBIDITY MEASURED IN PERCENT LIGHT TRANSMITTED THROUGH A TEN CENTIMETER WATER COLUMN.

DESCRIPTION	
REVISIONS	
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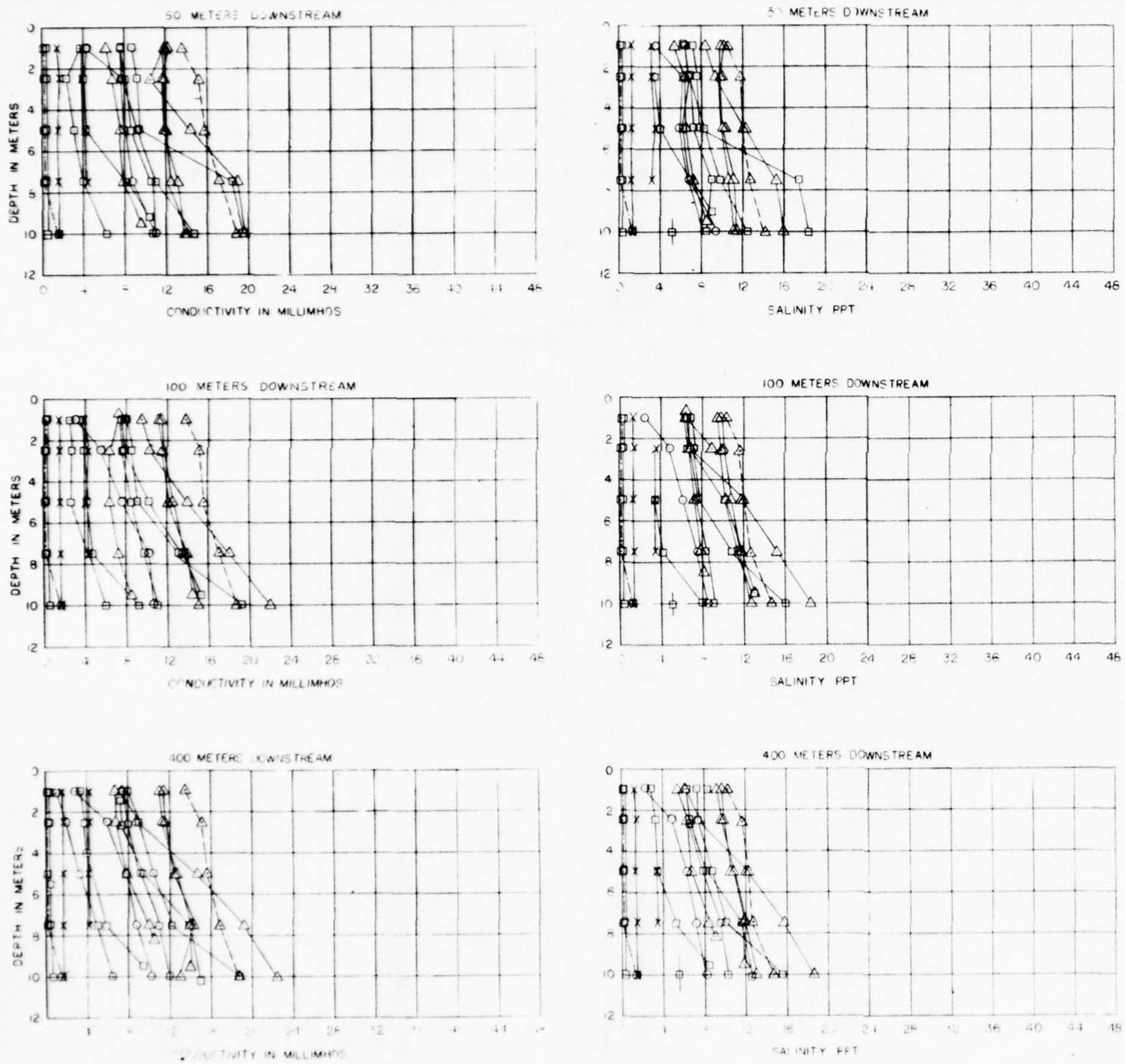
TRACED BY:	MARE ISLAND STRAIT
CHECKED BY: GP	WATER COLUMN STUDY
SUBMITTED: GP	TURBIDITY AND FTU STATION 4
PREPARED UNDER THE DIRECTION OF JAMES L. LAMMIE COLONEL, C.E., DISTRICT ENGINEER	

FIGURE 4 -12



LEGEND:

- PRE-DREDGING 22 JAN 74
- WHILE DREDGING 13,24,27 FEB 74 5,6,8,11,12,22,27 MAR 74
- POST DREDGING △ 1 MAY 74

□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
⬡ WET D.O.

NOTE:

1. 50, 100, AND 400 METER READINGS ARE TAKEN IN 5 MINUTE INTERVALS AND IN THE DIRECTION OF FLOW OF SURFACE CURRENT.

U.S. ARMY ENGINEER DISTRICT, SAN FRANCISCO
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MARE ISLAND STRAIT
WATER COLUMN STUDY
CONDUCTIVITY AND SALINITY

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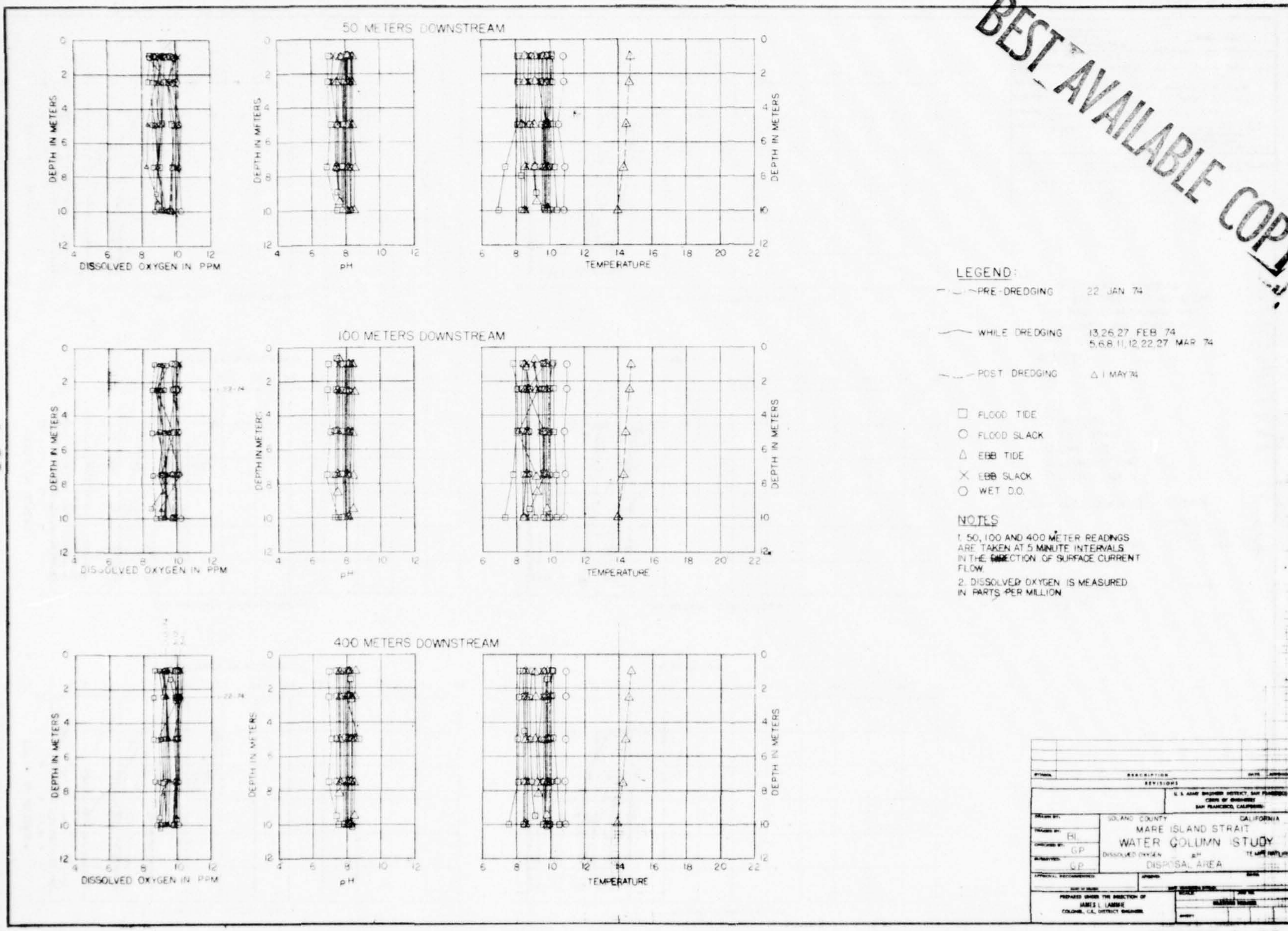
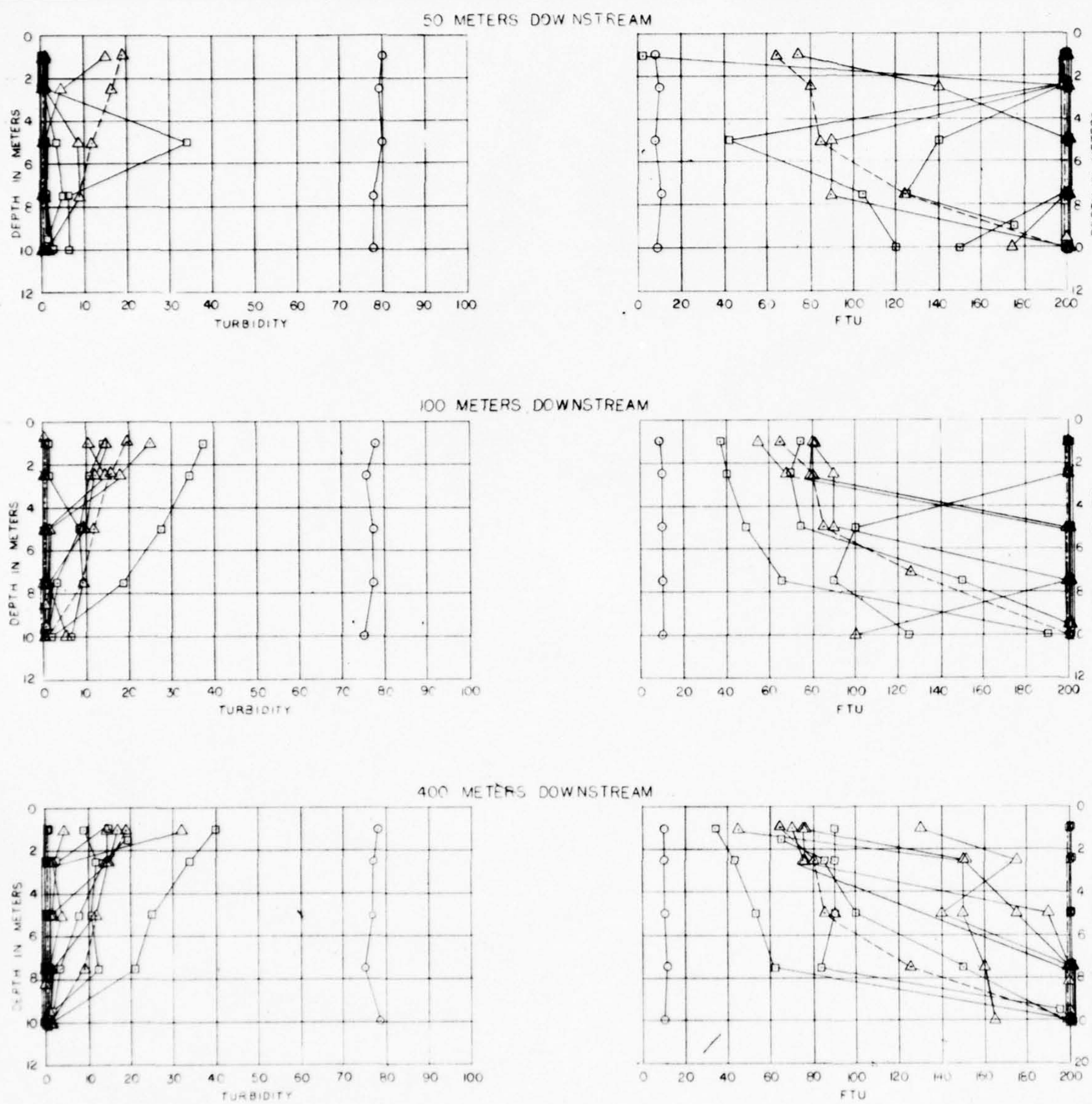
COLONEL, C.E. DISTRICT ENGINEER

FIGURE 4-13



50 METERS DOWNSTREAM
100 METERS DOWNSTREAM
400 METERS DOWNSTREAM
DEPTH IN METERS
DISSOLVED OXYGEN IN PPM
pH
TEMPERATURE
BEST AVAILABLE COPY
LEGEND:
PRE-DREDGING 22 JAN 74
WHILE DREDGING 13,26,27 FEB 74
5,6,8,11,12,22,27 MAR 74
POST DREDGING △ 1 MAY 74
□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
○ WET D.O.
NOTES
1. 50, 100 AND 400 METER READINGS ARE TAKEN AT 5 MINUTE INTERVALS IN THE DIRECTION OF SURFACE CURRENT FLOW.
2. DISSOLVED OXYGEN IS MEASURED IN PARTS PER MILLION
REVISIONS
SOLANO COUNTY CALIFORNIA
MARE ISLAND STRAIT
WATER COLUMN STUDY
DISPOSAL AREA

FIGURE 4-14



PRE DREDGING 22 JAN 74

WHILE DREDGING 13,26,27 FEB 74 5,6,8,11,12,22,27 MAR 74

POST DREDGING △ 1 MAY 74

□ FLOOD TIDE
○ FLOOD SLACK
△ EBB TIDE
× EBB SLACK
○ WET DO

NOTES:

1. 50, 100, AND 400 METER READINGS ARE TAKEN IN 5 MINUTE INTERVALS AND IN THE DIRECTION OF FLOW OF SURFACE CURRENTS.
2. TURBIDITY MEASURED IN PERCENT LIGHT TRANSMITTED THROUGH A TEN CENTIMETER WATER COLUMN.

SYMBOL	DESCRIPTION	DATE	APPROVAL
	REVISIONS		

U. S. ARMY ENGINEER DISTRICT, SAN FRANCISCO
CORPS OF ENGINEERS
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SOLANO COUNTY CALIFORNIA
MARE ISLAND STRAIT
WATER COLUMN STUDY
TURBIDITY AND FTU

APPROVAL RECOMMENDED: APPROVED: DATE:

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JAMES L. LAMMIE
COLONEL, C.E., DISTRICT ENGINEER

SCALE: FILE NO.: DRAWING NUMBER: SHEET:

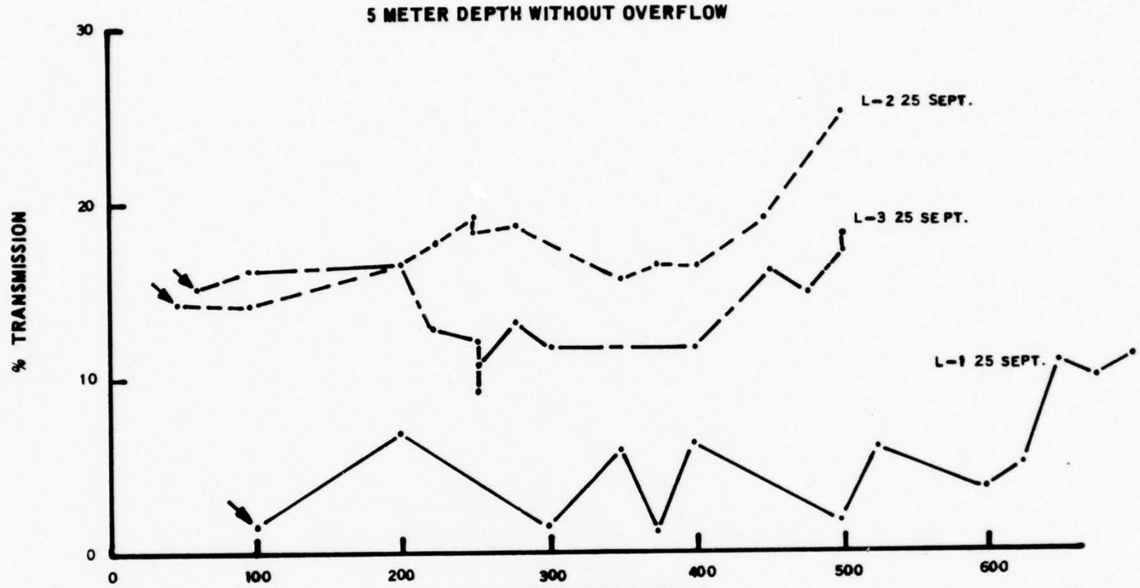
FIGURE 4-13

INCLOSURE 5

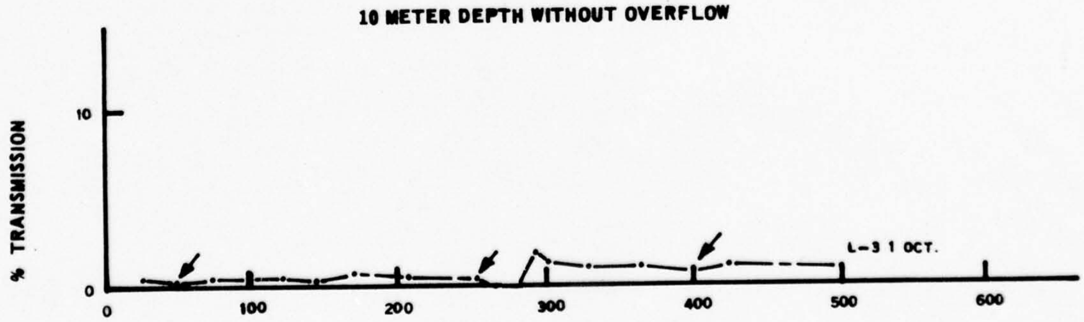
Per Cost Transmission Data
from Plume Definition Study

MARE ISLAND STRAIT - HOPPER DREDGING

5 METER DEPTH WITHOUT OVERFLOW

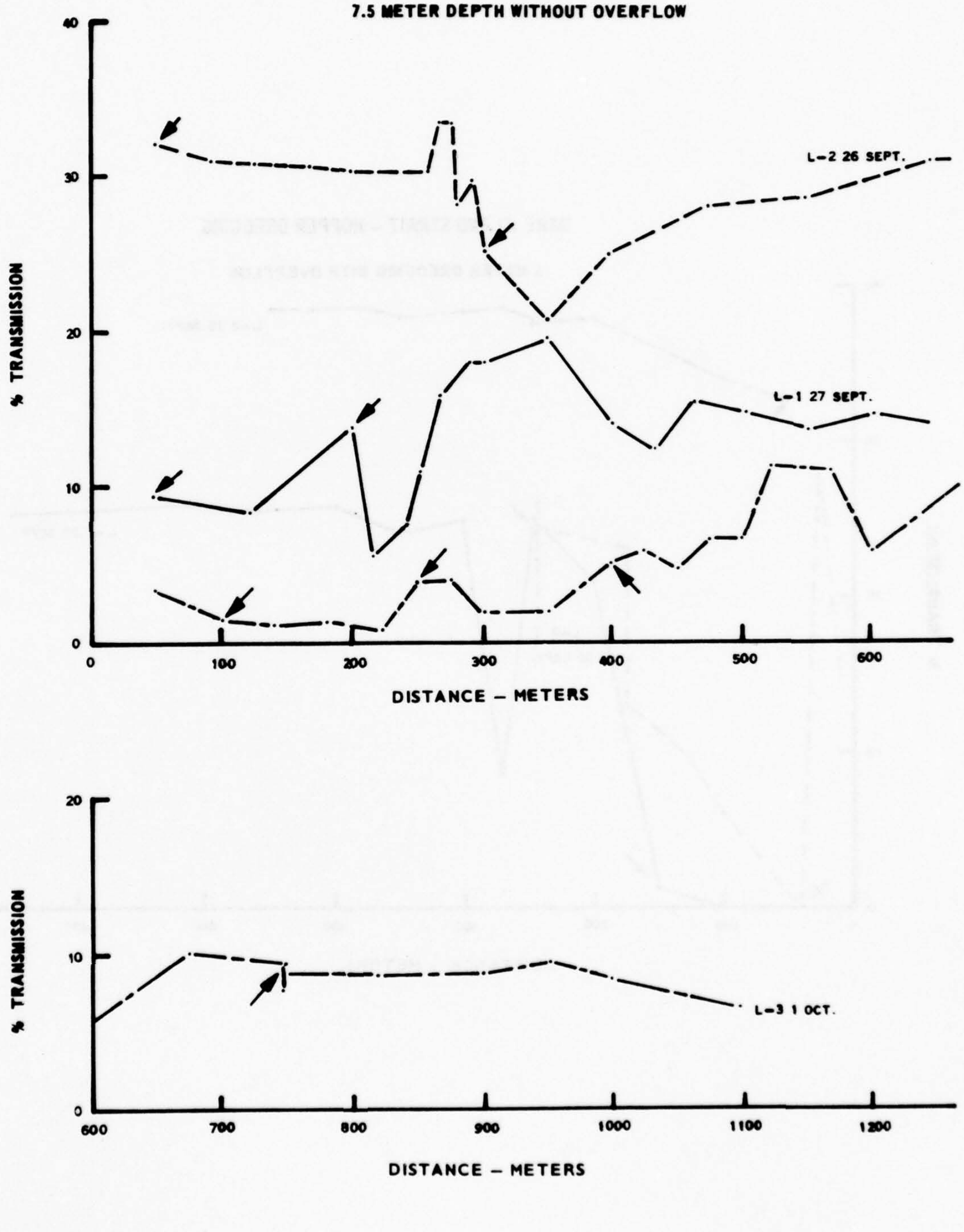


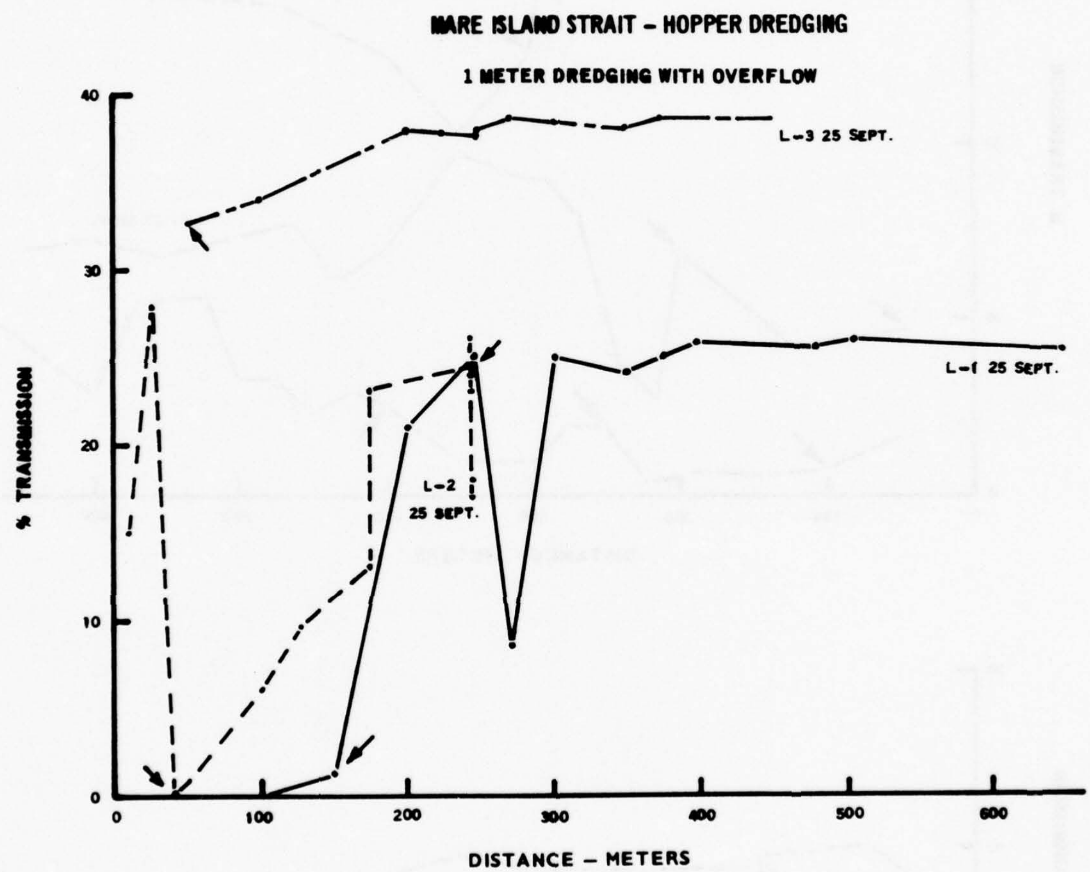
10 METER DEPTH WITHOUT OVERFLOW



MARE ISLAND STRAIT – HOPPER DREDGING

7.5 METER DEPTH WITHOUT OVERFLOW

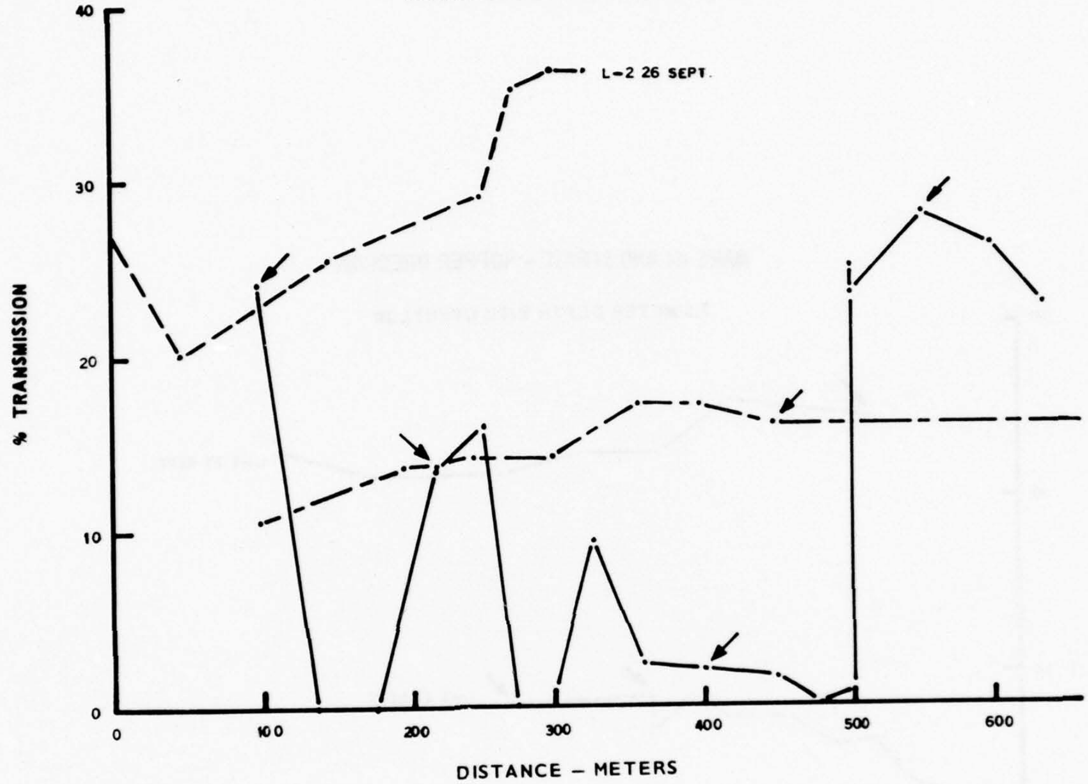


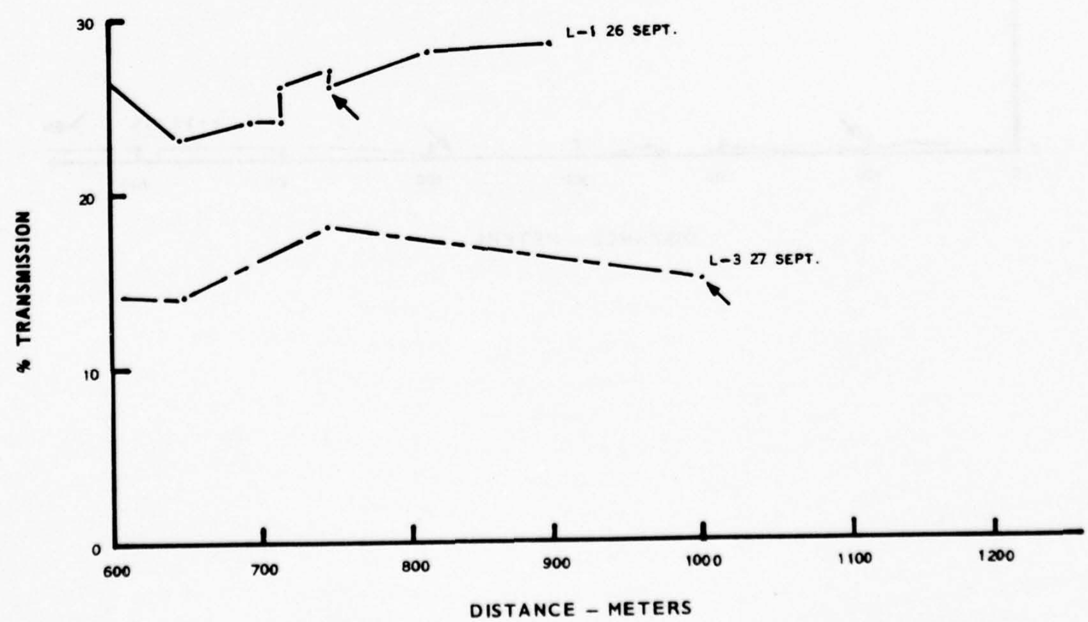


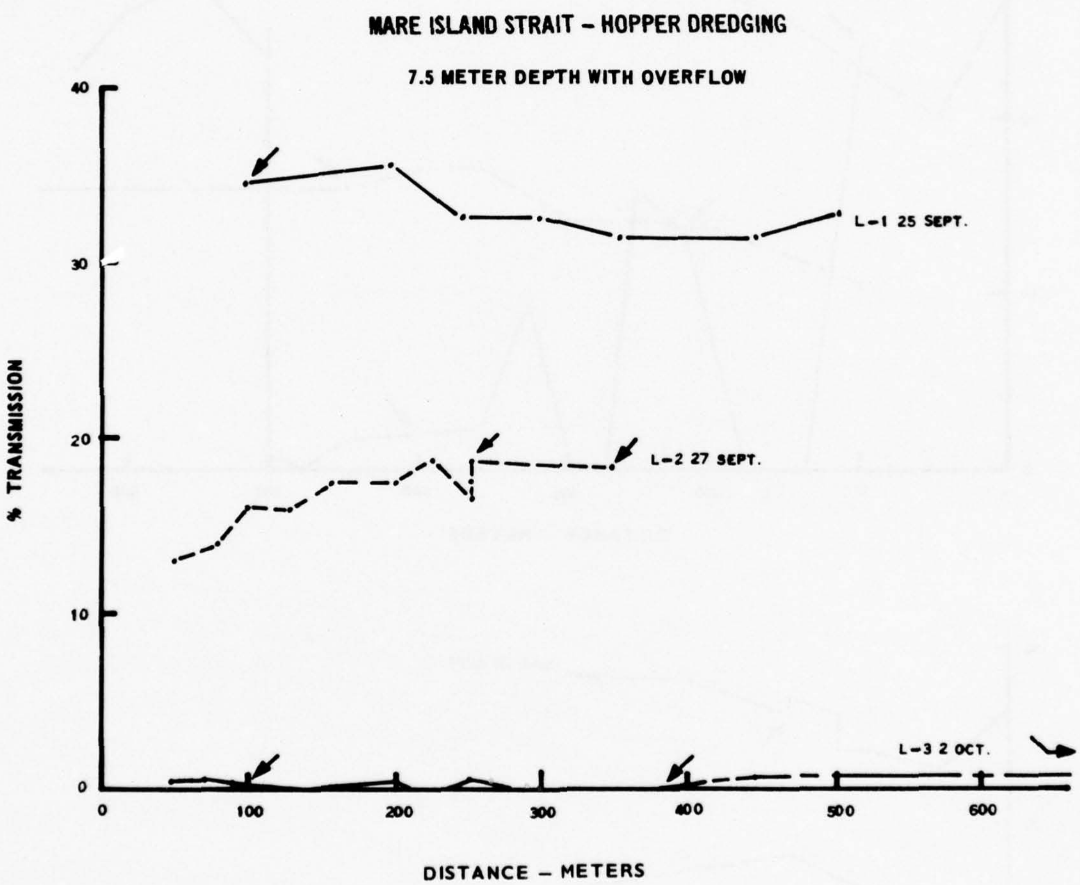
MARE ISLAND STRAIT - HOPPER DREDGING
1 METER DREDGING WITH OVERFLOW
40
30
20
10
0
% TRANSMISSION
L-3 25 SEPT.
L-1 25 SEPT.
L-2
25 SEPT.
0
100
200
300
400
500
600
DISTANCE - METERS

MARE ISLAND STRAIT – HOPPER DREDGING

2.5 METER DEPTH WITH OVERFLOW

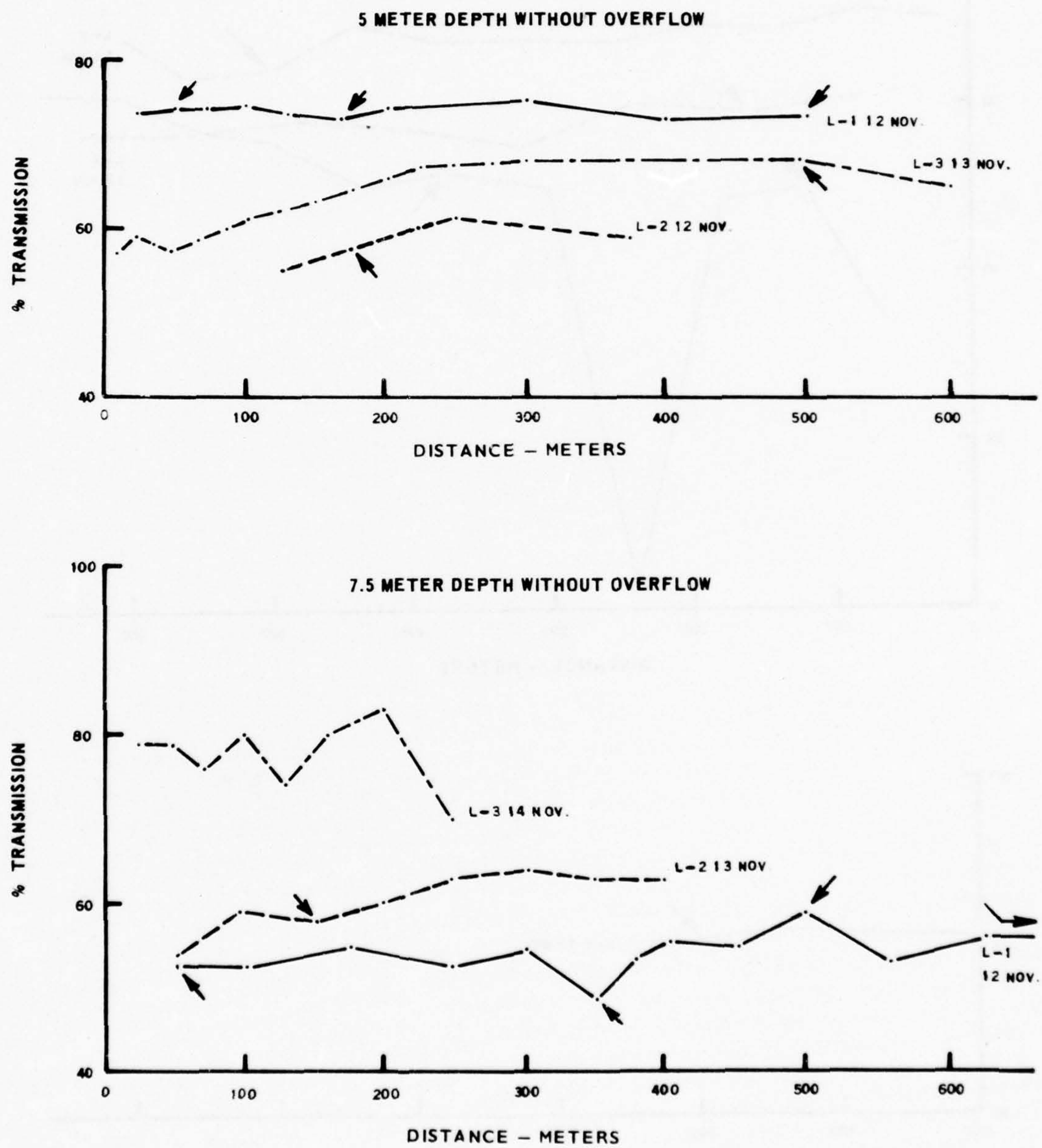






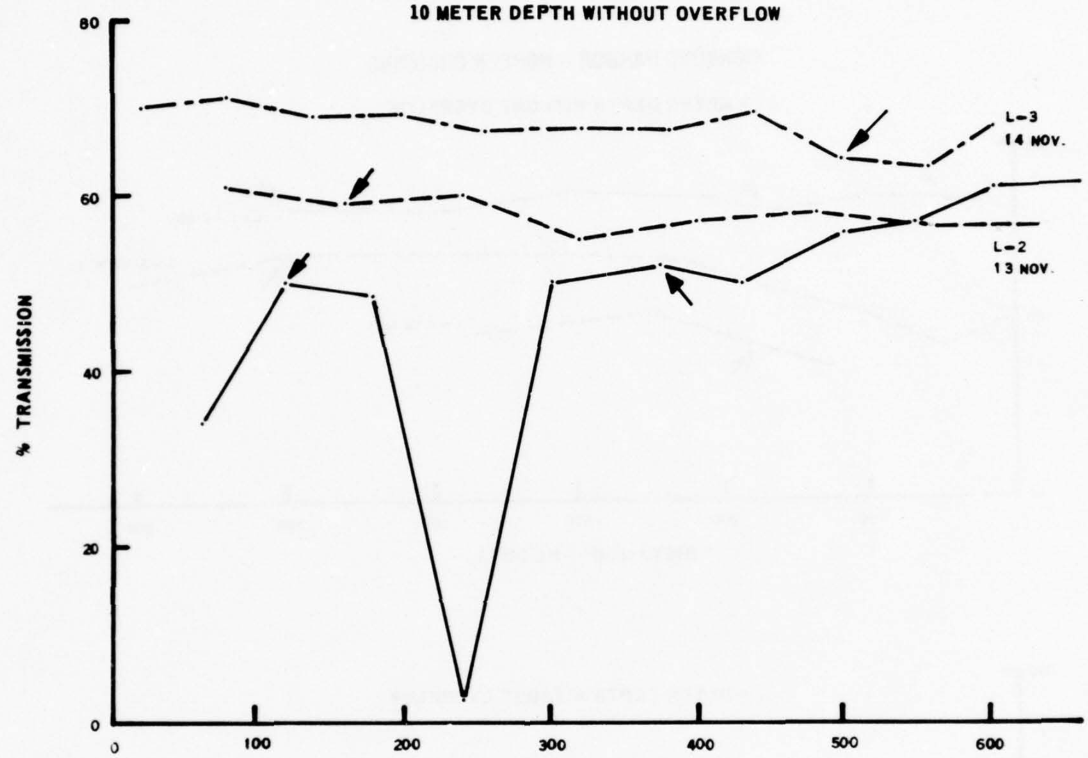
MARE ISLAND STRAIT – HOPPER DREDGING
7.5 METER DEPTH WITH OVERFLOW
% TRANSMISSION
40
30
20
10
0
L-1 25 SEPT.
L-2 27 SEPT.
L-3 2 OCT.
0
100
200
300
400
500
600
DISTANCE – METERS

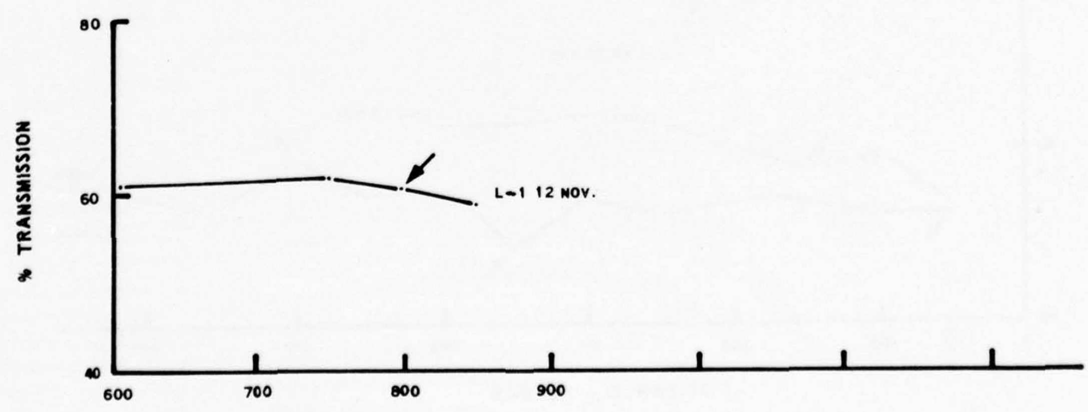
RICHMOND HARBOR – HOPPER DREDGING

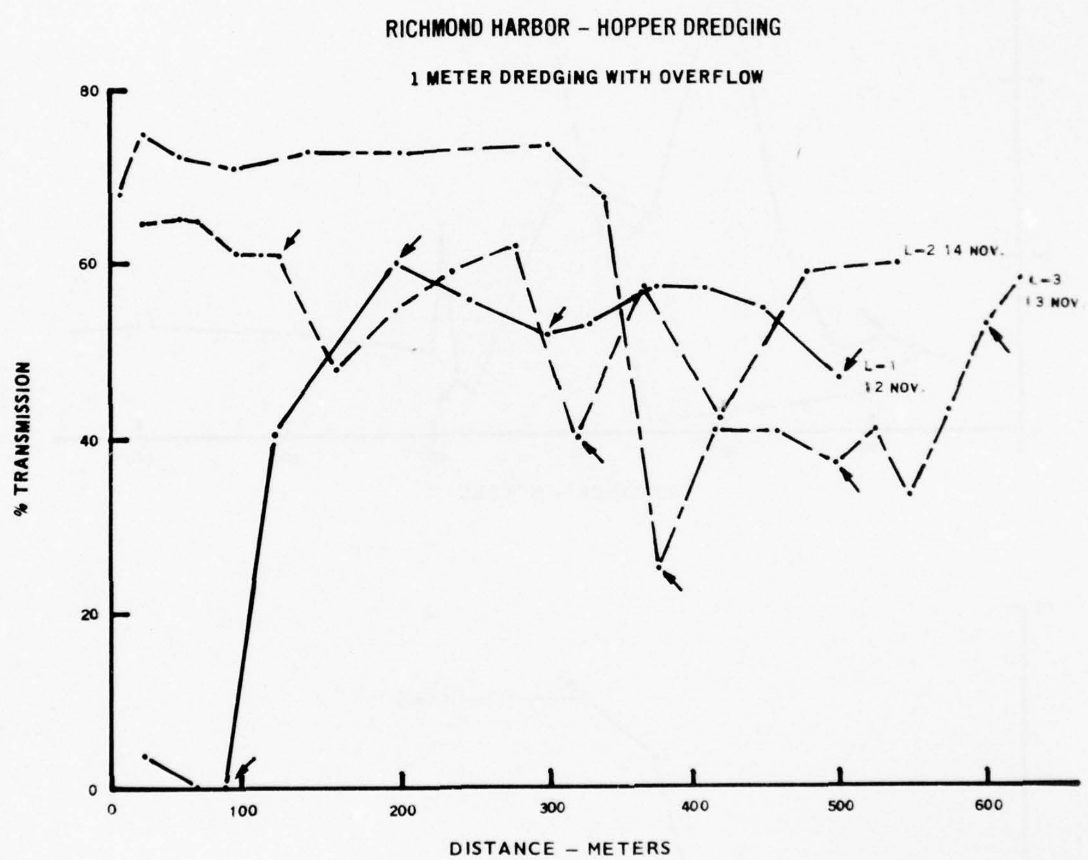


RICHMOND HARBOR – HOPPER DREDGING

10 METER DEPTH WITHOUT OVERFLOW



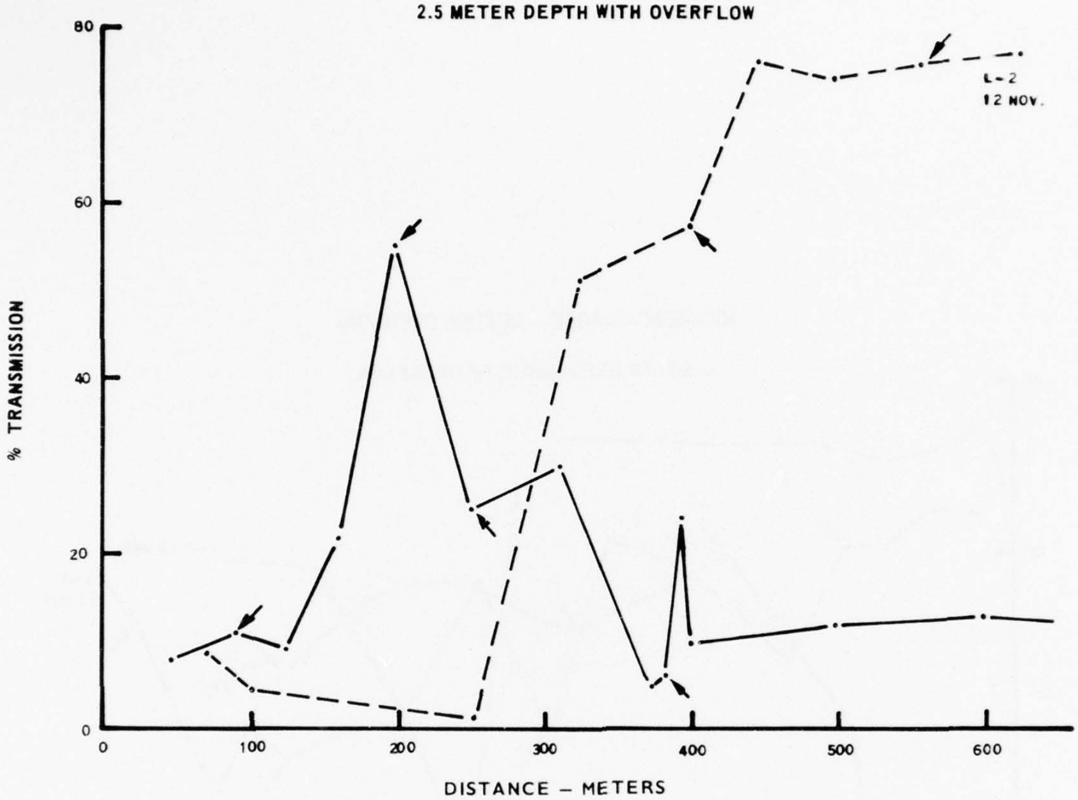


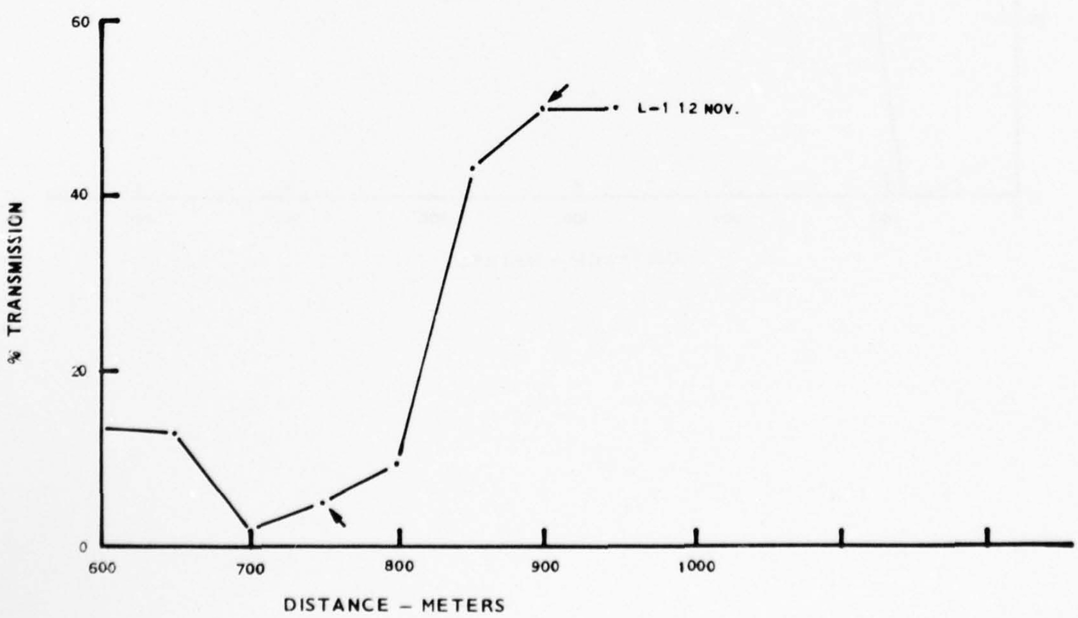


RICHMOND HARBOR – HOPPER DREDGING
1 METER DREDGING WITH OVERFLOW
% TRANSMISSION
80
60
40
20
0
0
100
200
300
400
500
600
DISTANCE – METERS
L–2 14 NOV.
L–3
13 NOV.
L–1
12 NOV.

RICHMOND HARBOR – HOPPER DREDGING

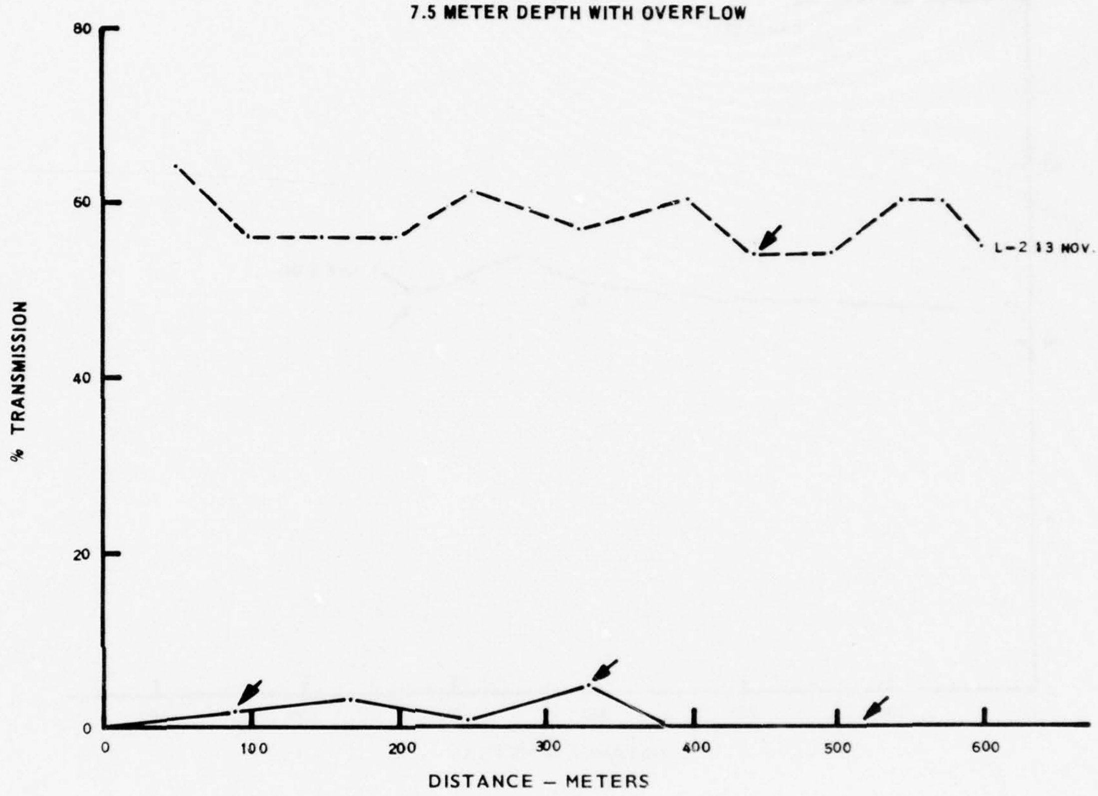
2.5 METER DEPTH WITH OVERFLOW

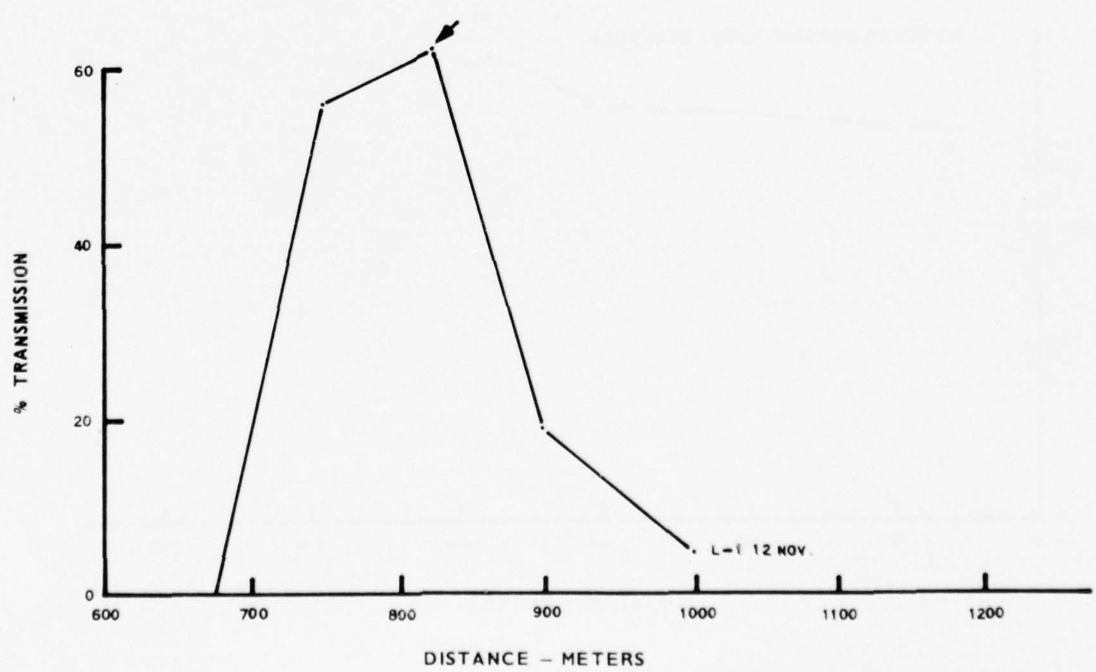




RICHMOND HARBOR – HOPPER DREDGING

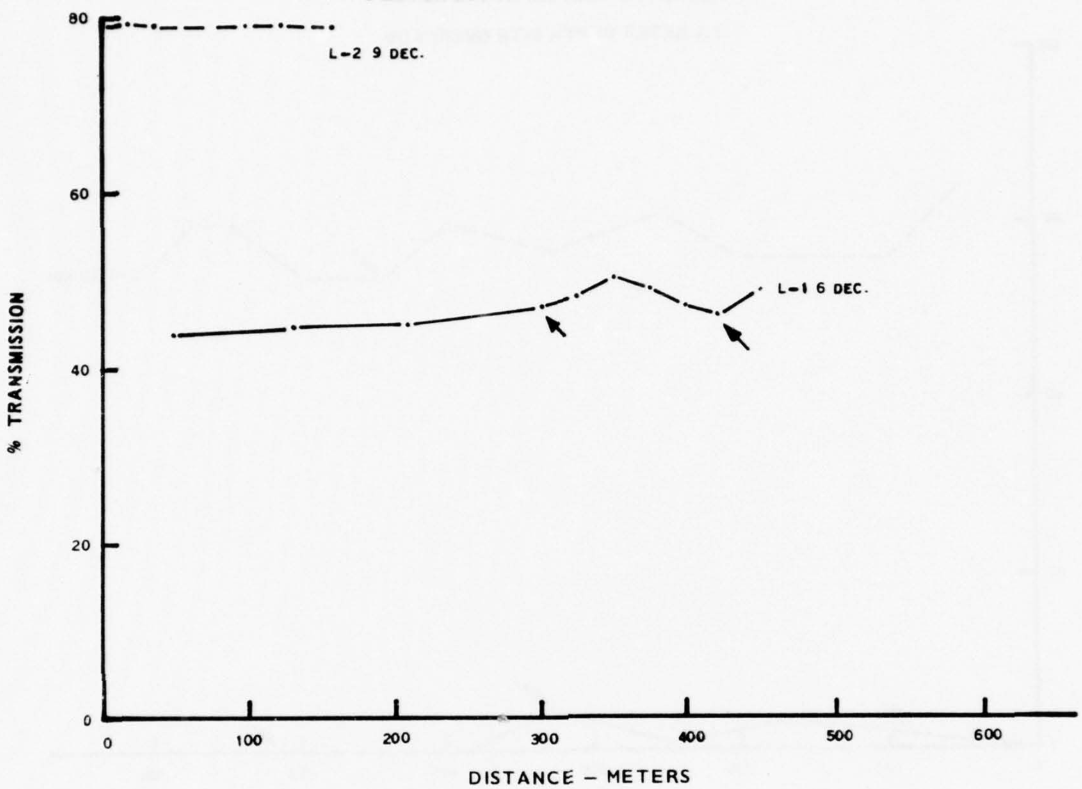
7.5 METER DEPTH WITH OVERFLOW



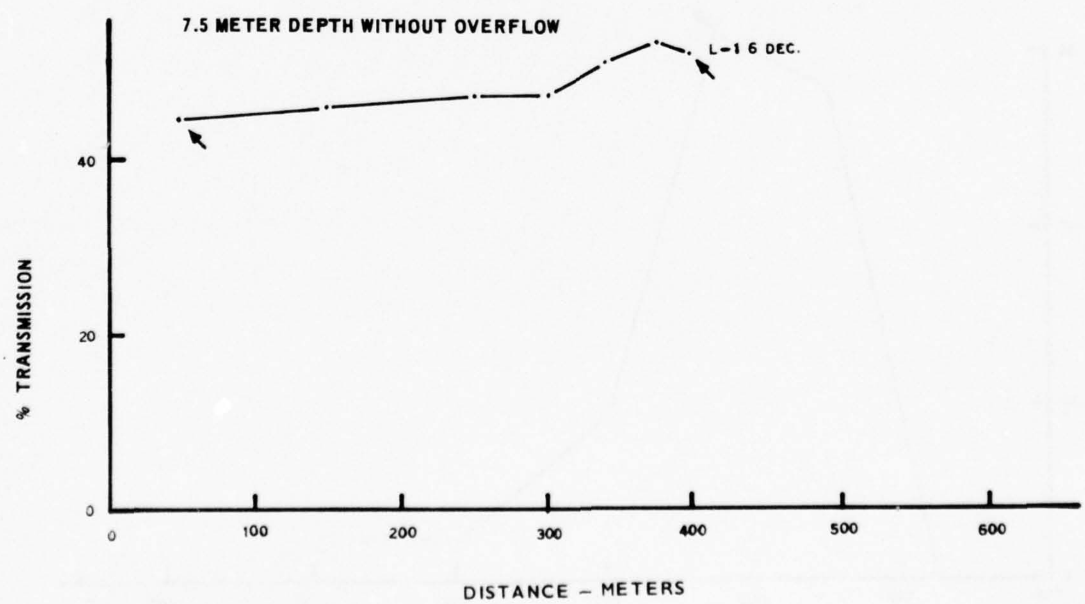


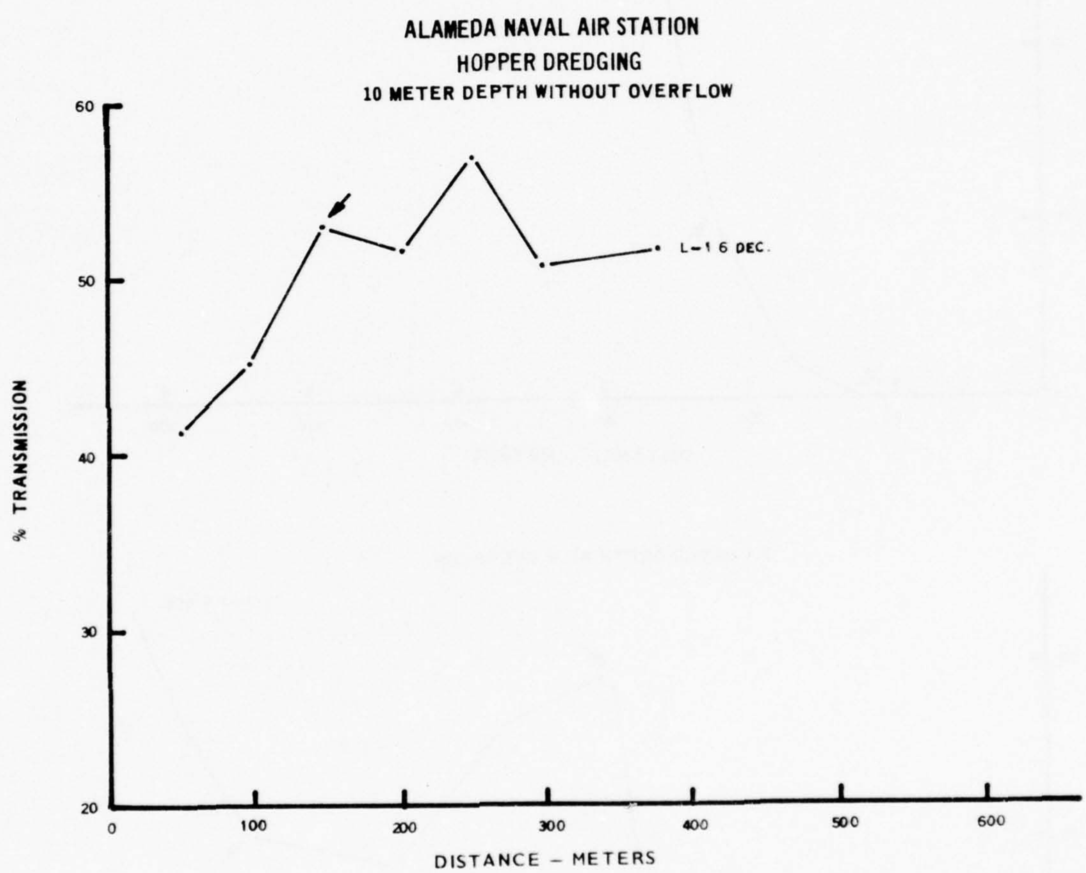
ALAMEDA NAVAL AIR STATION
HOPPER DREDGING

5 METER DEPTH WITHOUT OVERFLOW



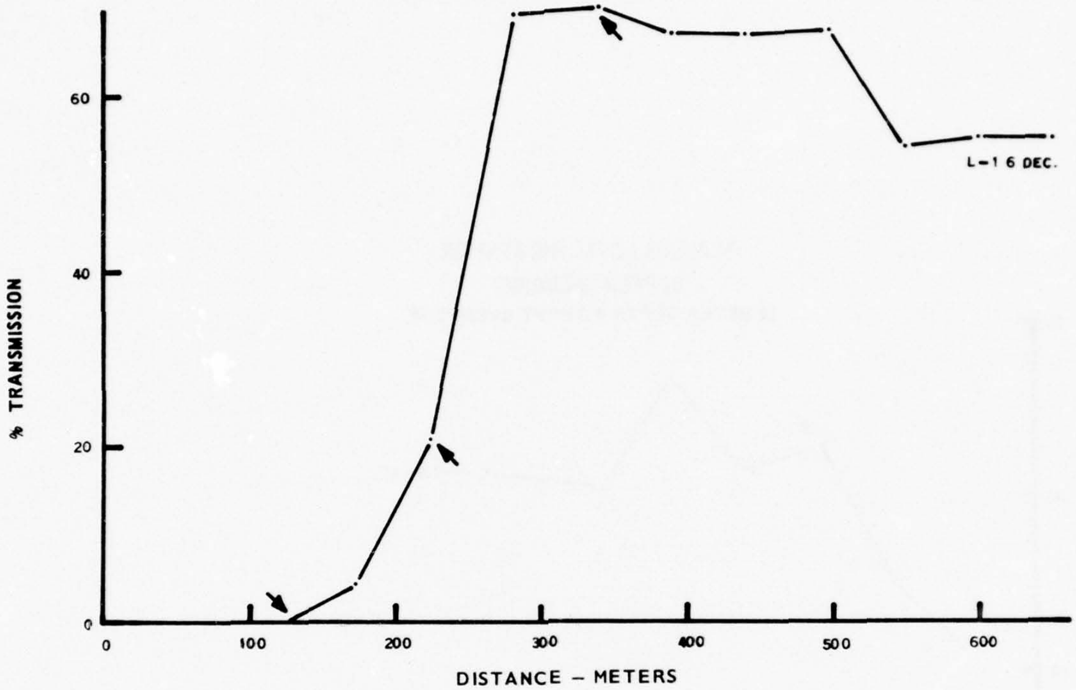
7.5 METER DEPTH WITHOUT OVERFLOW



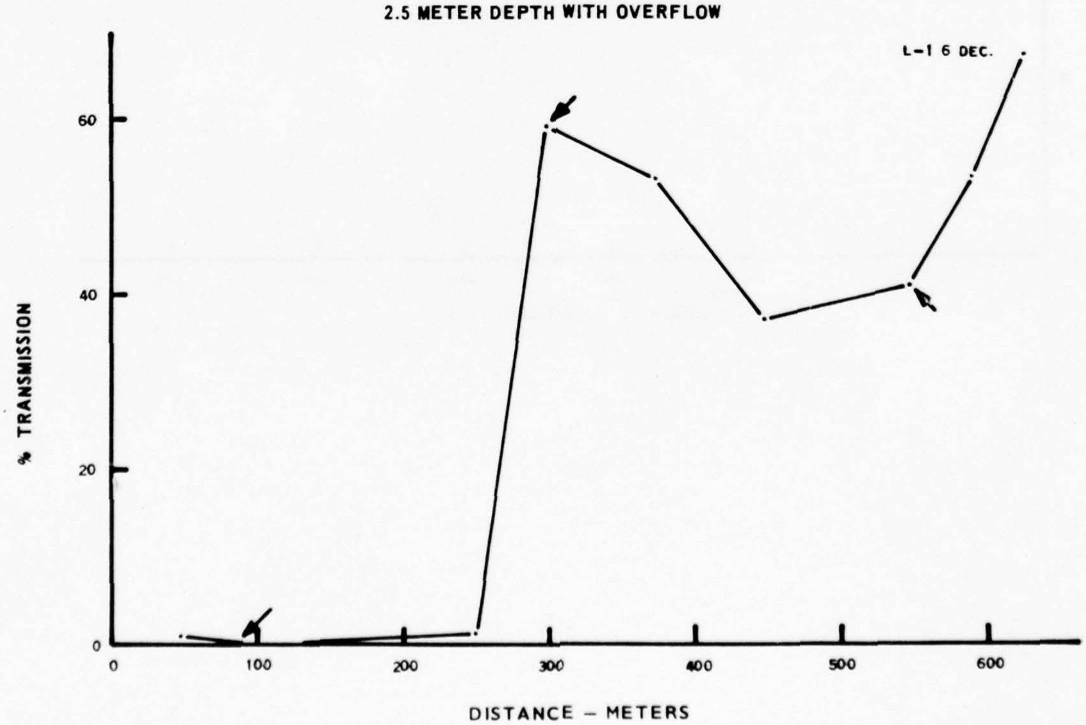

ALAMEDA NAVAL AIR STATION
HOPPER DREDGING
10 METER DEPTH WITHOUT OVERFLOW
60
50
40
30
20
% TRANSMISSION
L-1 6 DEC.
0
100
200
300
400
500
600
DISTANCE – METERS

ALAMEDA NAVAL AIR STATION
HOPPER DREDGING

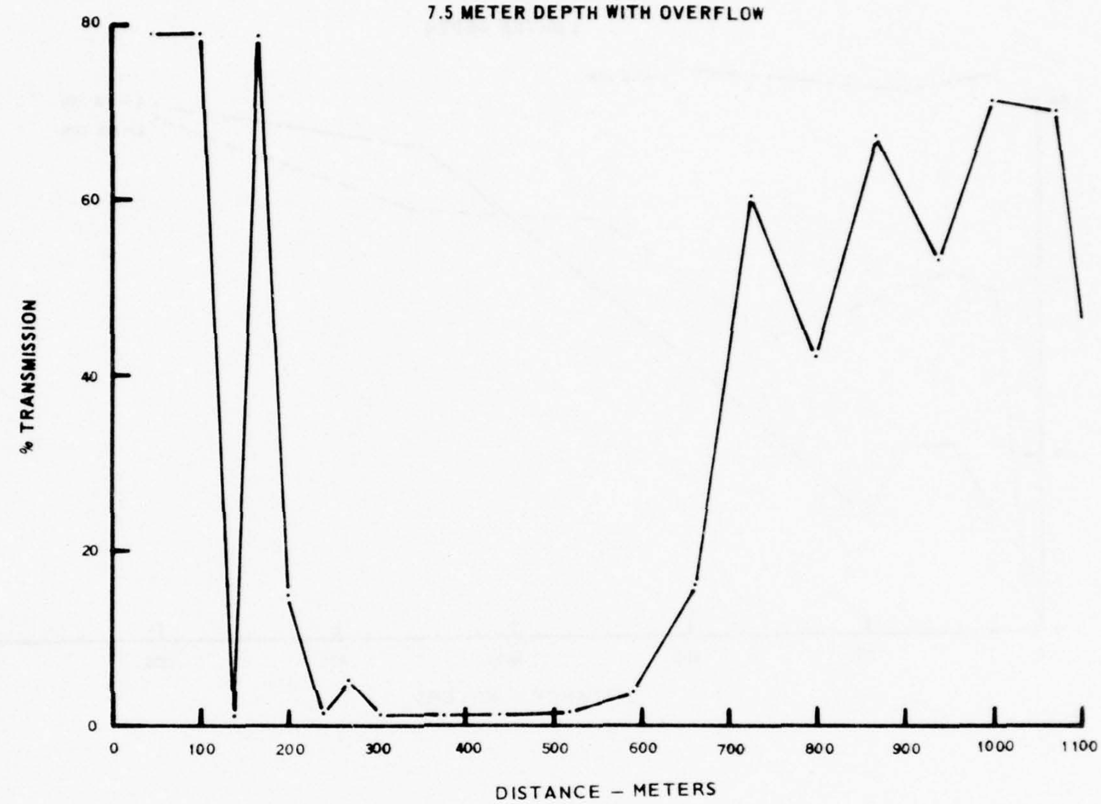
1 METER DEPTH WITH OVERFLOW

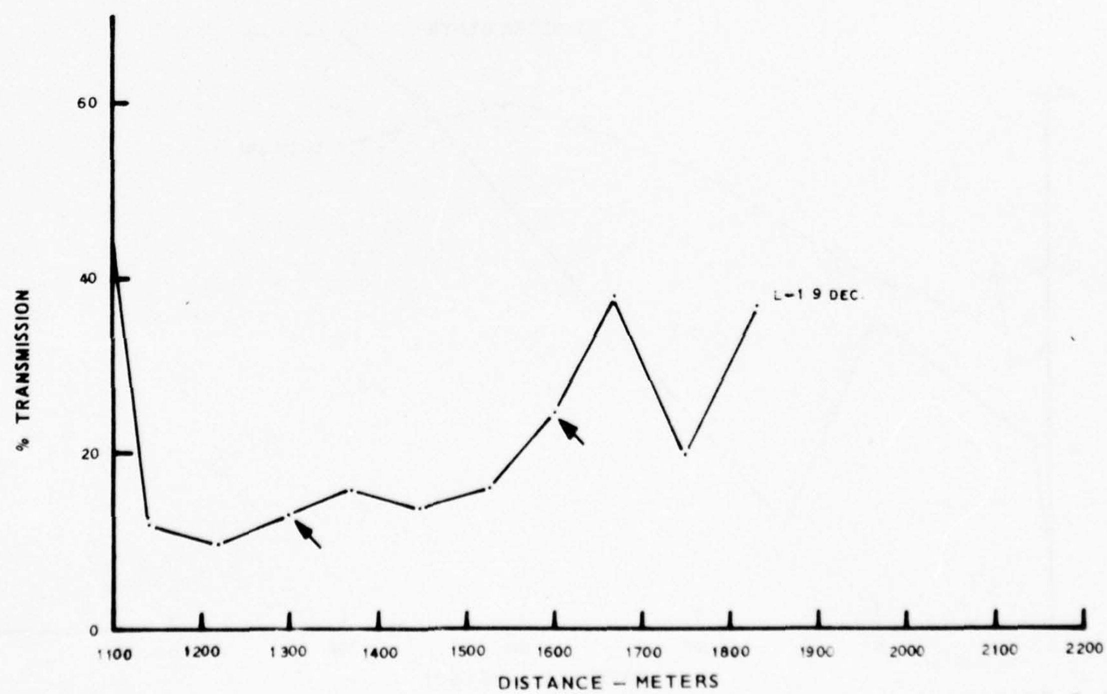


2.5 METER DEPTH WITH OVERFLOW



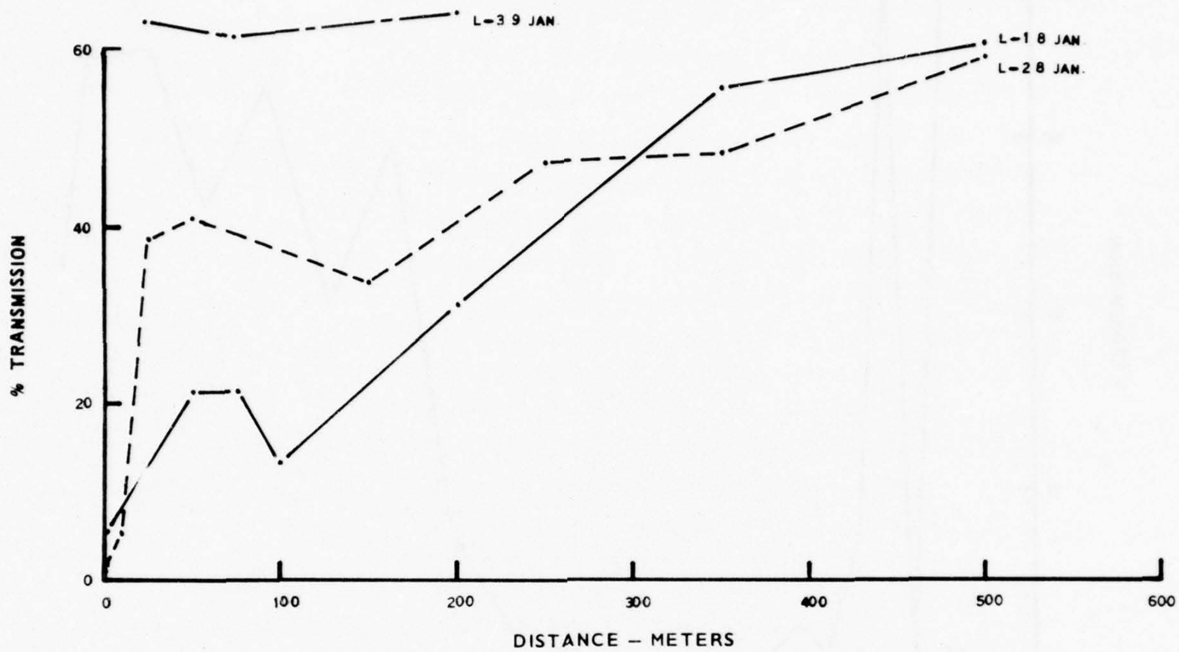
ALAMEDA NAVAL AIR STATION
HOPPER DREDGING
7.5 METER DEPTH WITH OVERFLOW



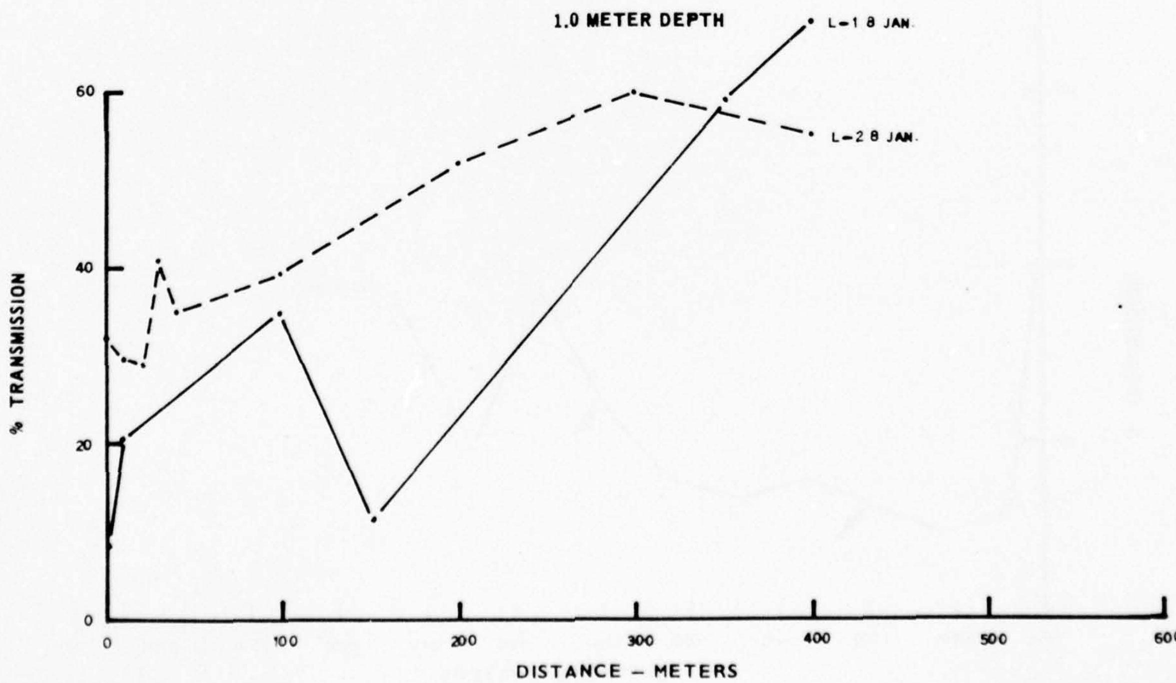


ALAMEDA CLAM DREDGE

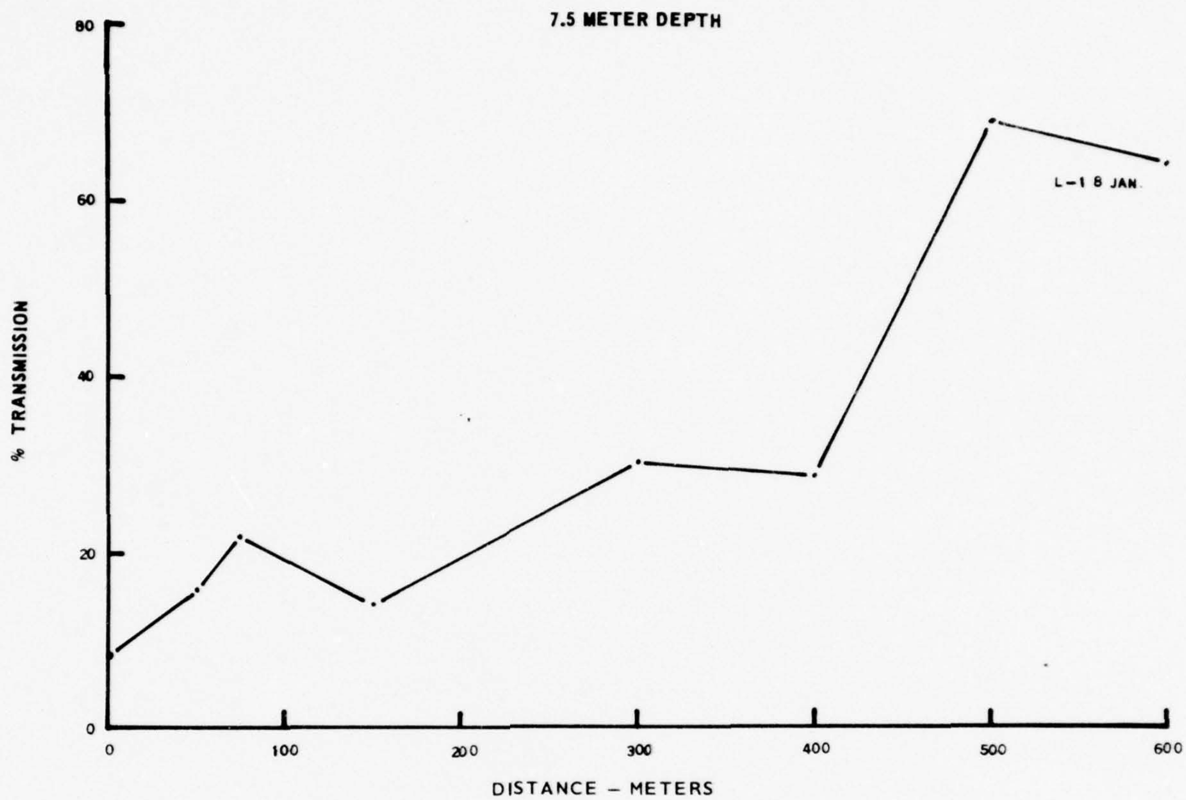
5 METER DEPTH

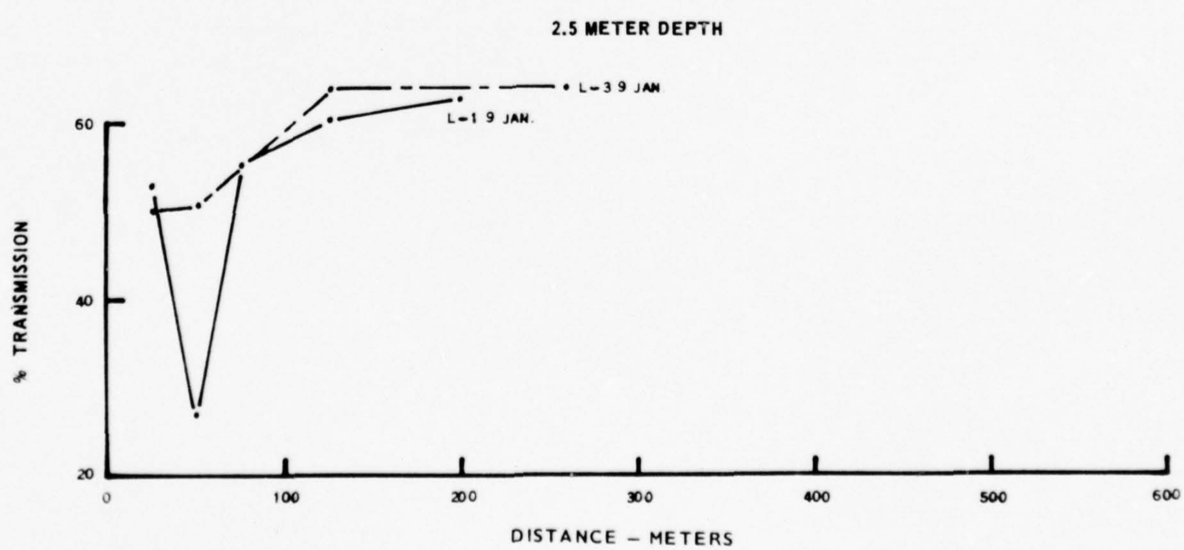


1.0 METER DEPTH



ALAMEDA CLAM DREDGE





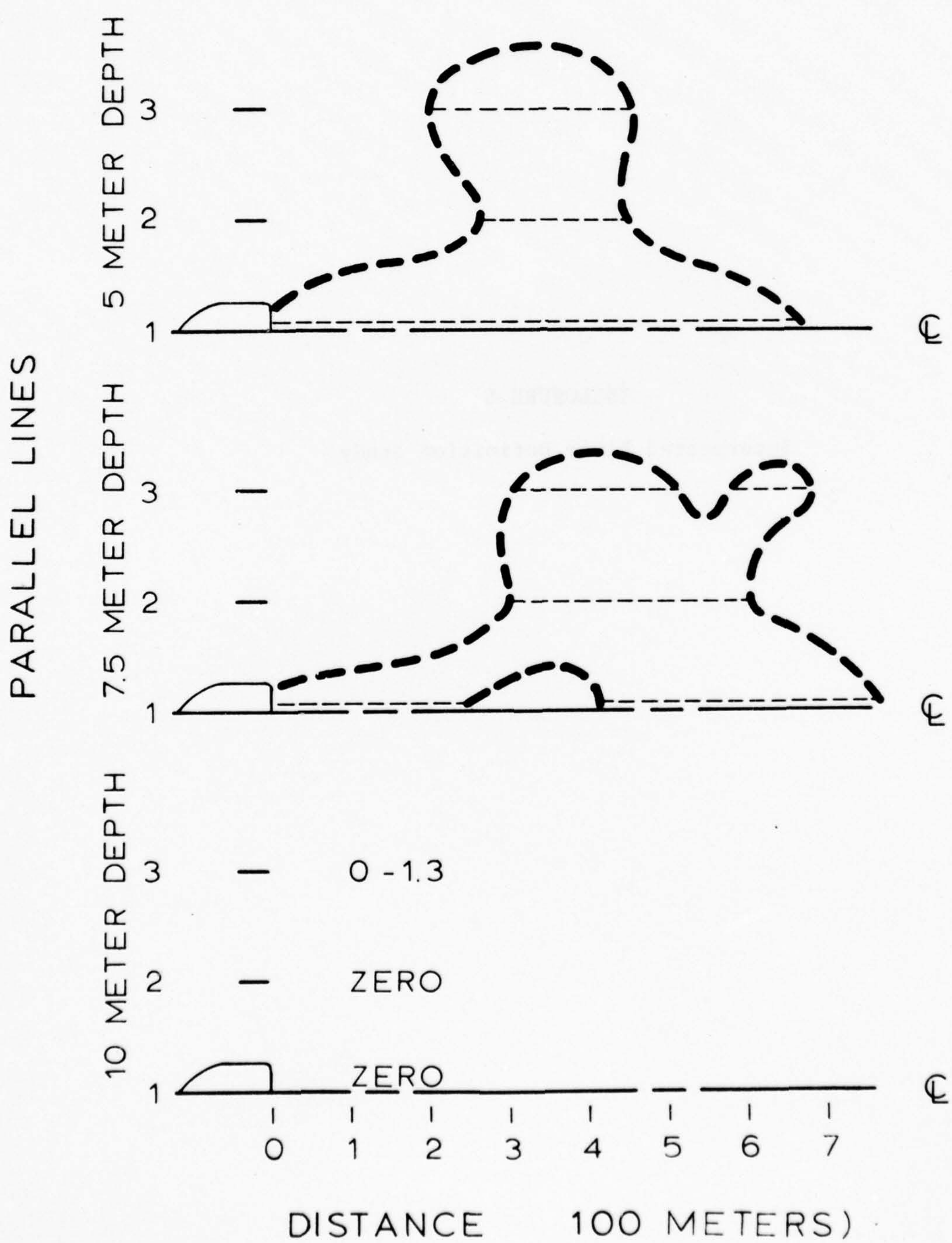
INCLOSURE 6

Interpreted Plume Definition Study

HOPPER DREDGE - MARE ISLAND STRAIT

TURBIDITY PLUME WITHOUT OVERFLOW Sep-Oct 74

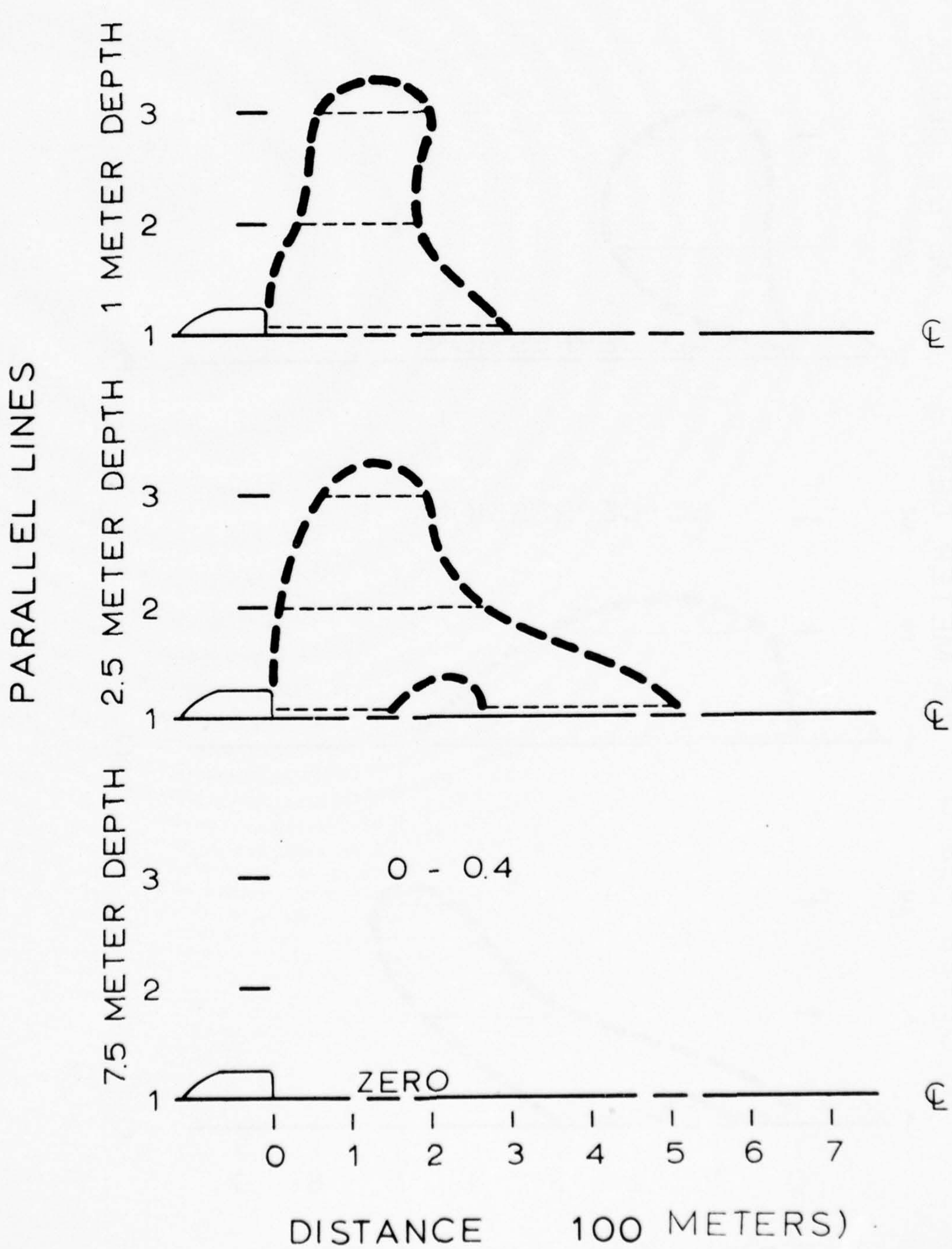
USING 10 CENTIMETER LIGHT PATH



HOPPER DREDGE - MARE ISLAND STRAIT

TURBIDITY PLUME WITH OVERFLOW Sep-Oct 74

USING 10 CENTIMETER LIGHT PATH

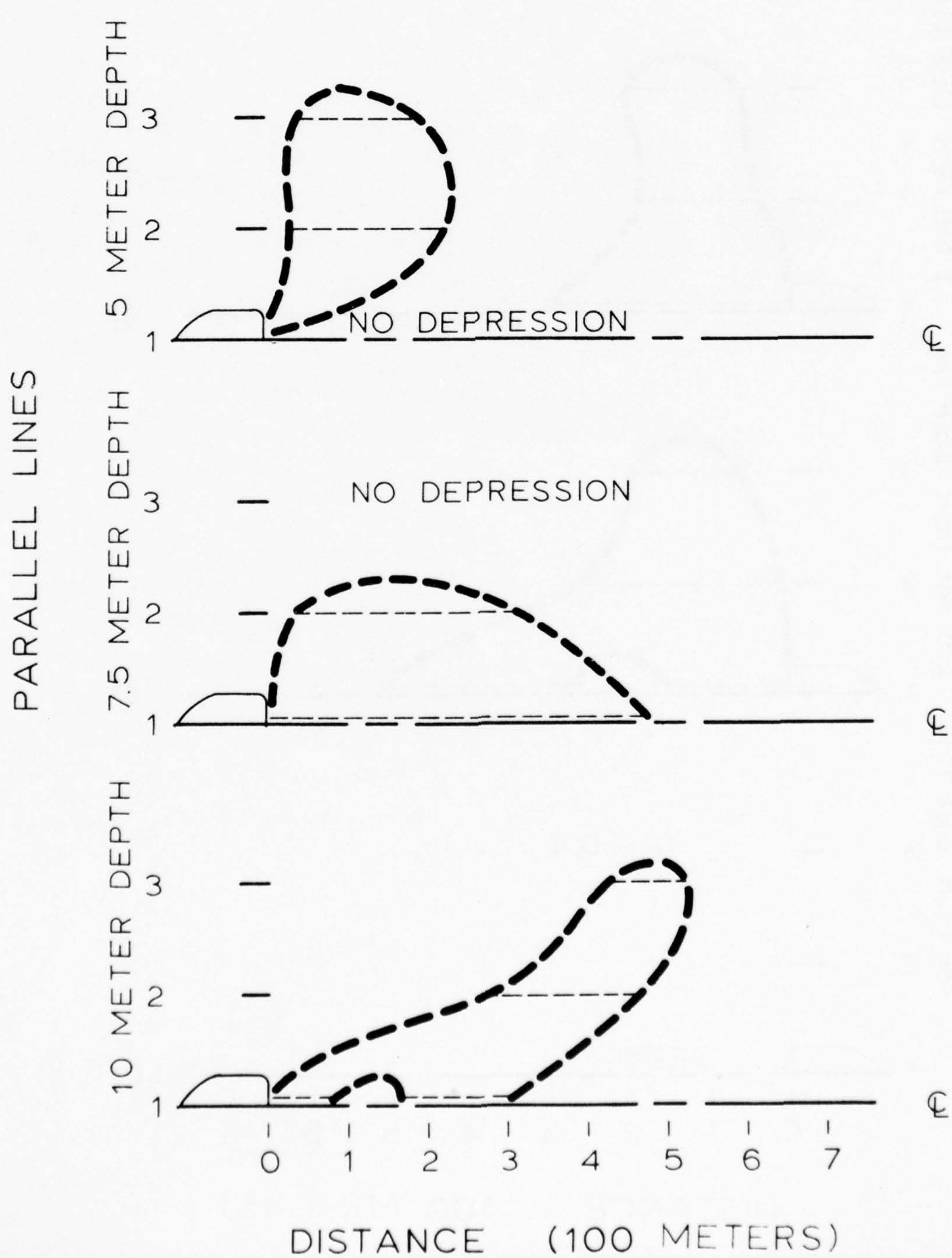


INCLOSURE 6-2

HOPPER DREDGE - RICHMOND HARBOR

TURBIDITY PLUME WITHOUT OVERFLOW Nov 74

USING 10 CENTIMETER LIGHT PATH

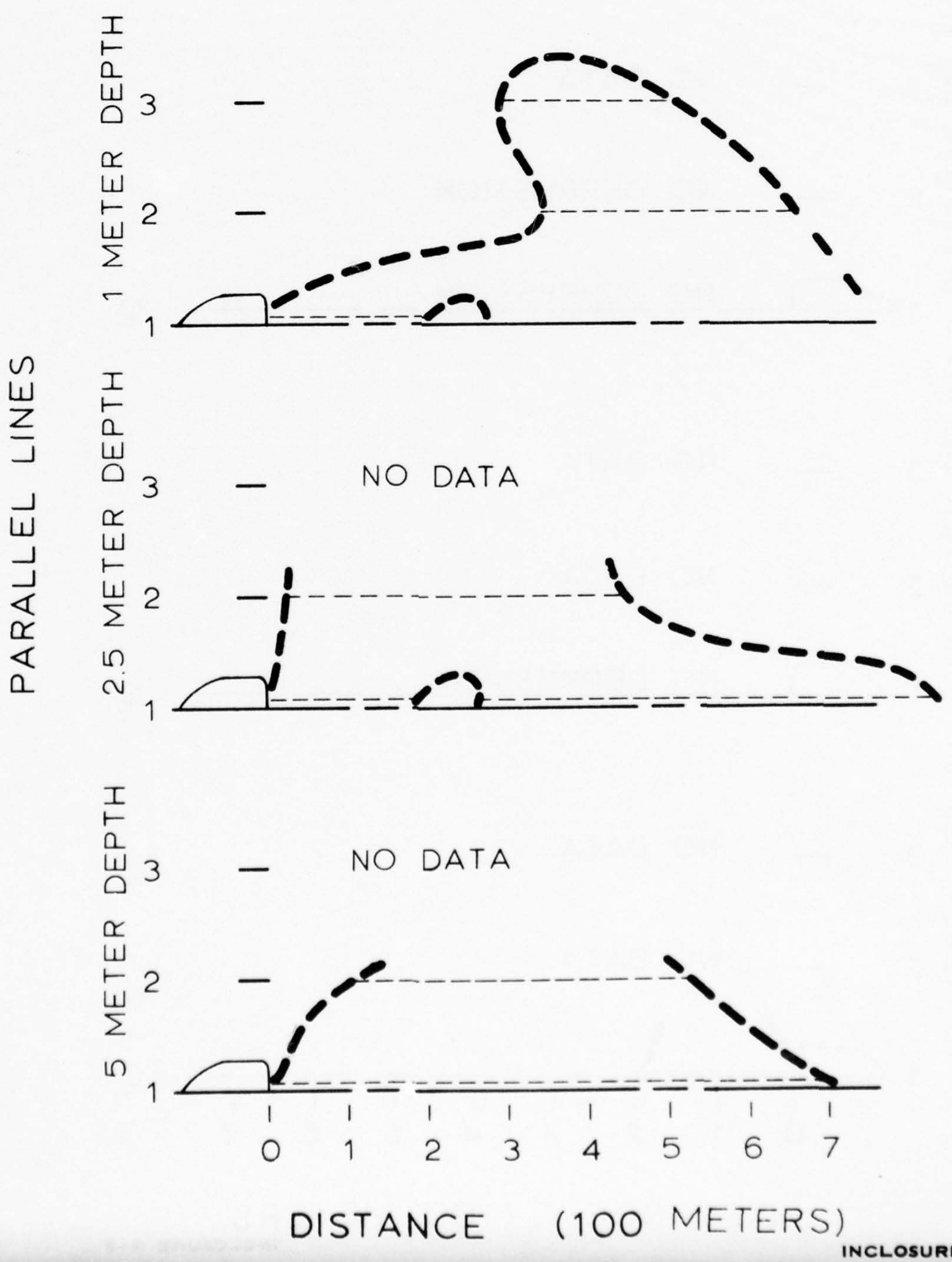


INCLOSURE 6-3

HOPPER DREDGE - RICHMOND HARBOR

TURBIDITY PLUME WITH OVERFLOW Nov 74

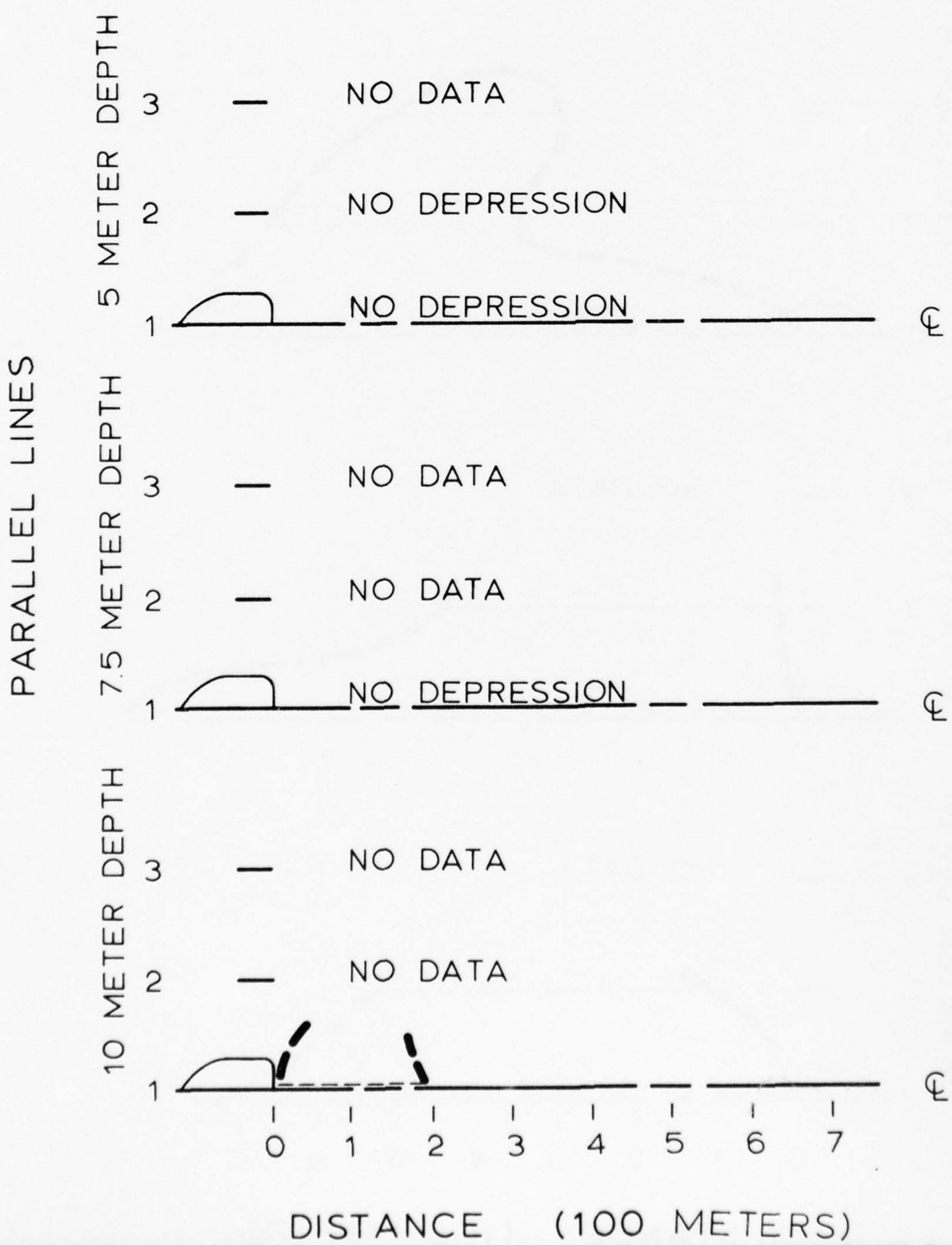
USING 10 CENTIMETER LIGHT PATH



HOPPER DREDGE - ALAMEDA NAVAL AIR STATION

TURBIDITY PLUME WITHOUT OVERFLOW Dec 74

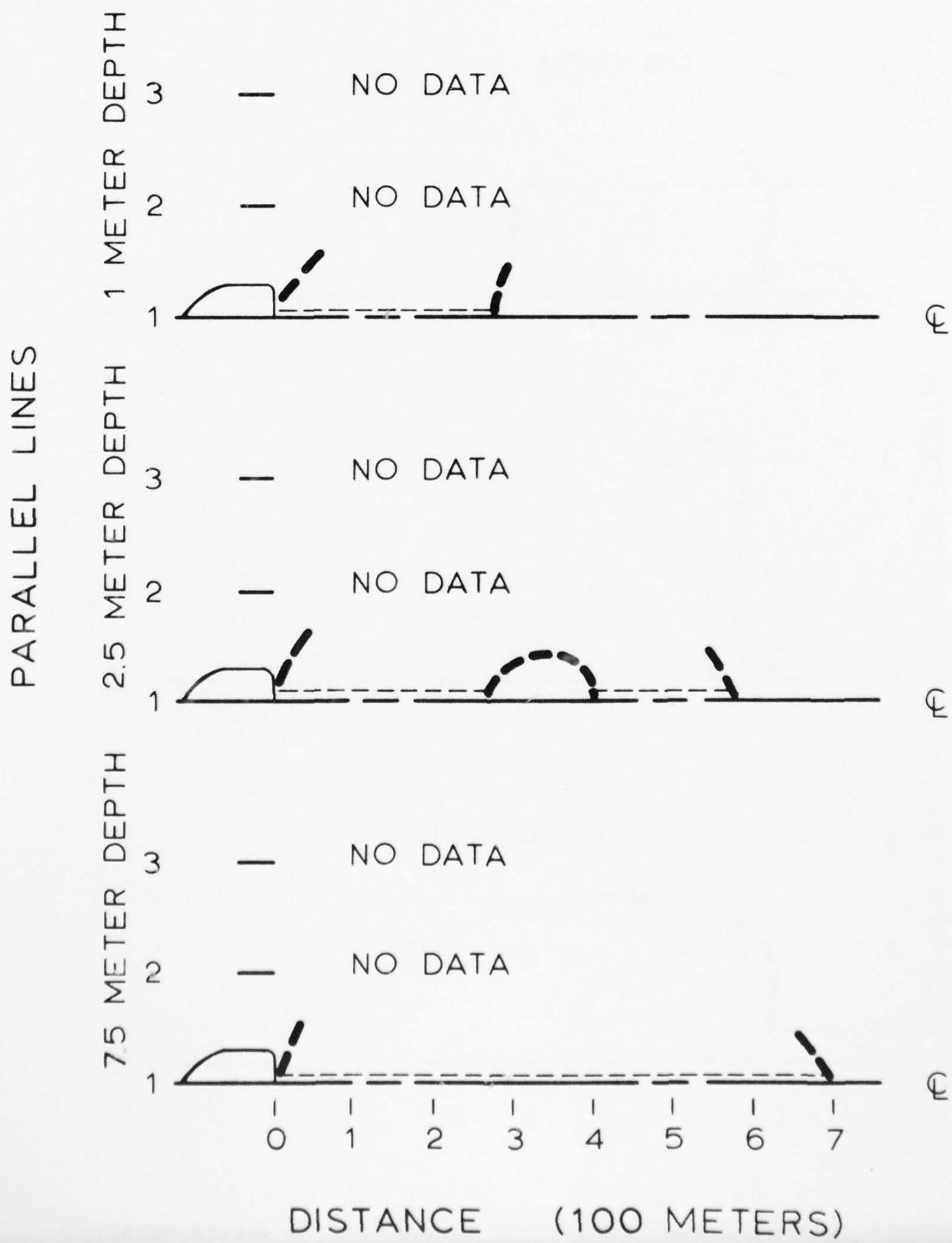
USING 10 CENTIMETER LIGHT PATH



INCLOSURE 6-5

HOPPER DREDGE - ALAMEDA NAVAL AIR STATION

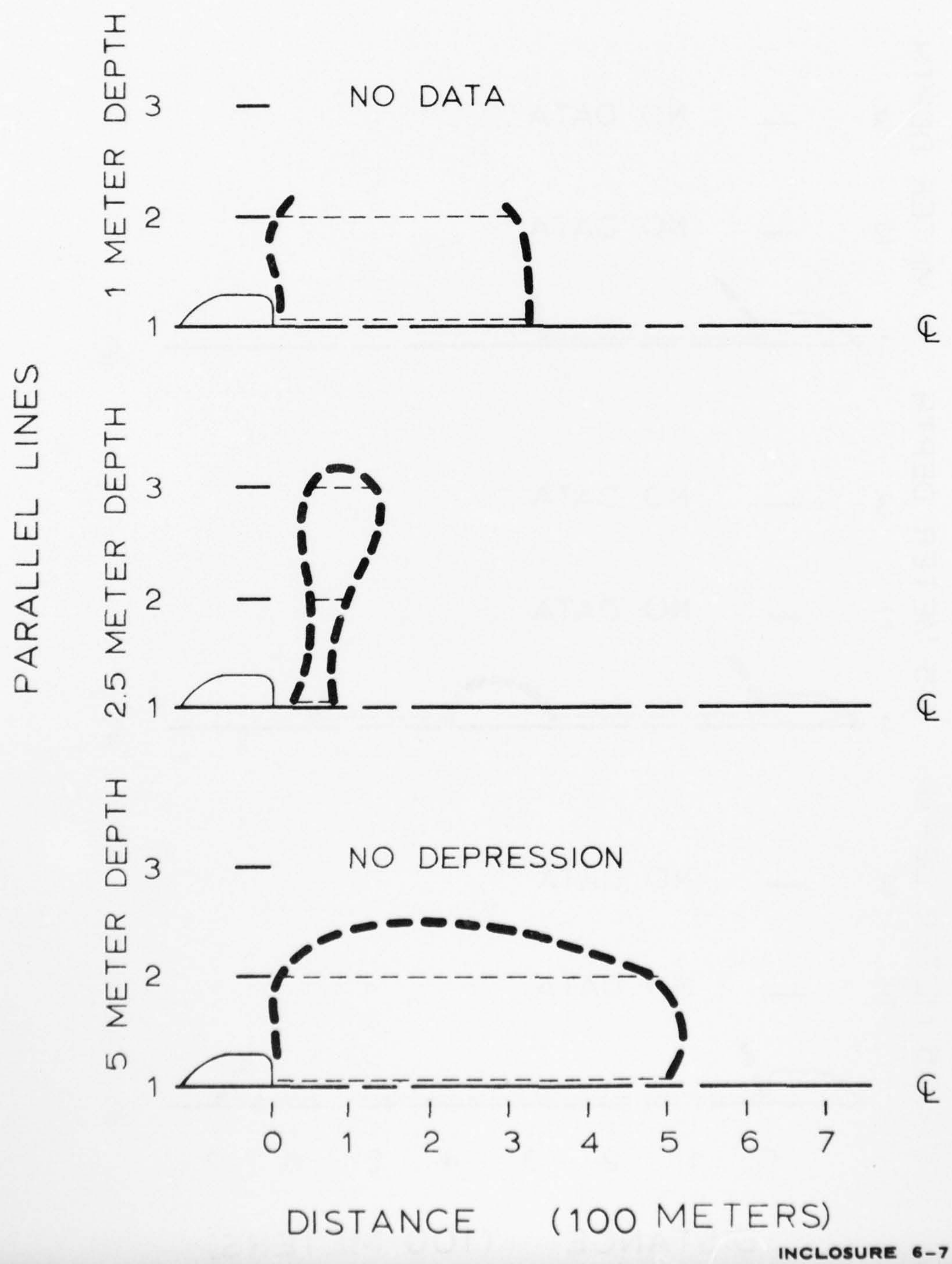
TURBIDITY PLUME WITH OVERFLOW Dec 74
(USING 10 CENTIMETER LIGHT PATH)



INCLOSURE 6-6

CLAMSHELL DREDGE - ALAMEDA NAVAL AIR STATION

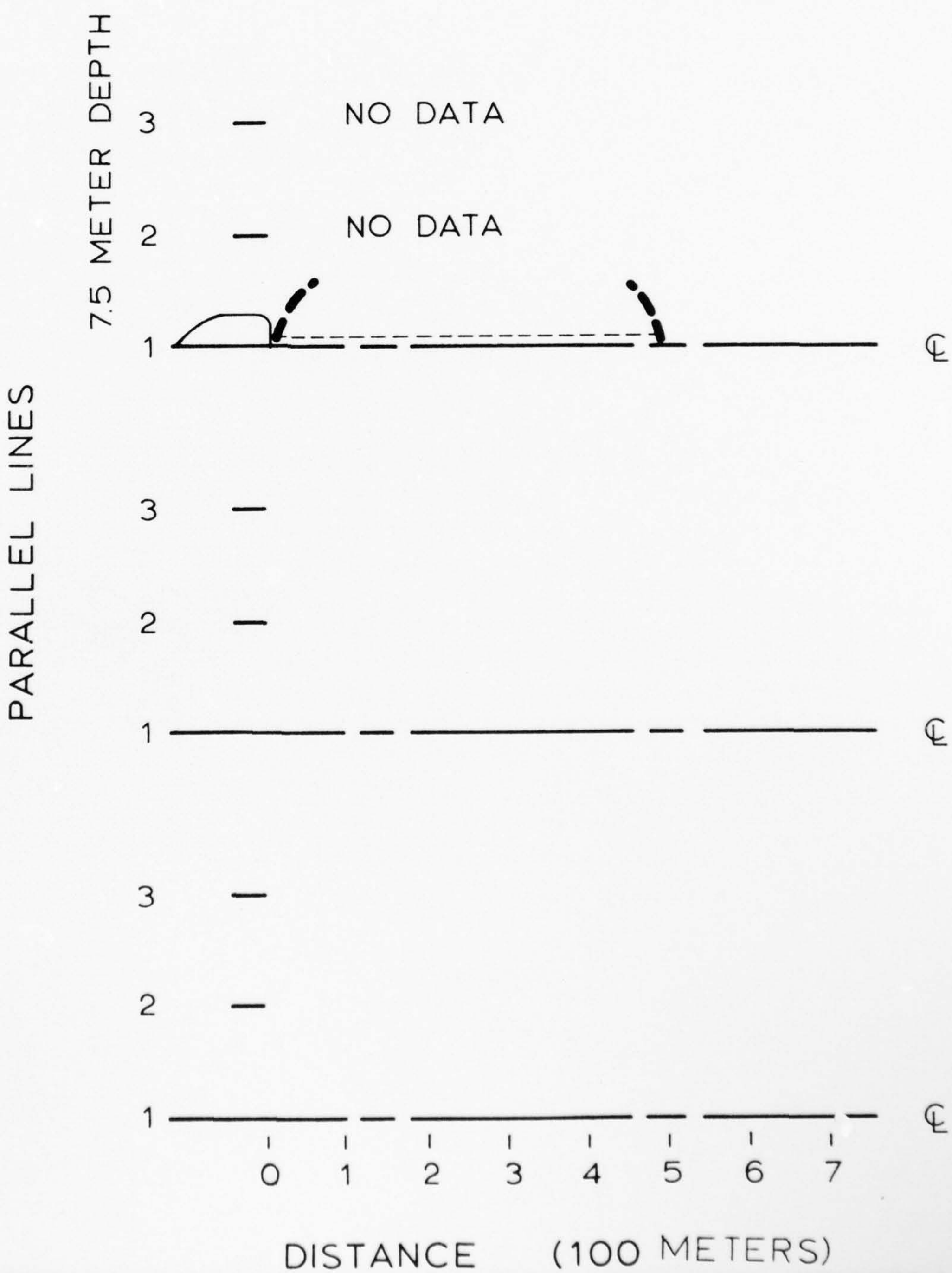
TURBIDITY PLUME (USING 10 CENTIMETER LIGHT PATH)
Jan 75



CLAMSHELL DREDGE ALAMEDA NAVAL AIR STATION

TURBIDITY PLUME (USING 10 CENTIMETER LIGHT PATH

Jan 75



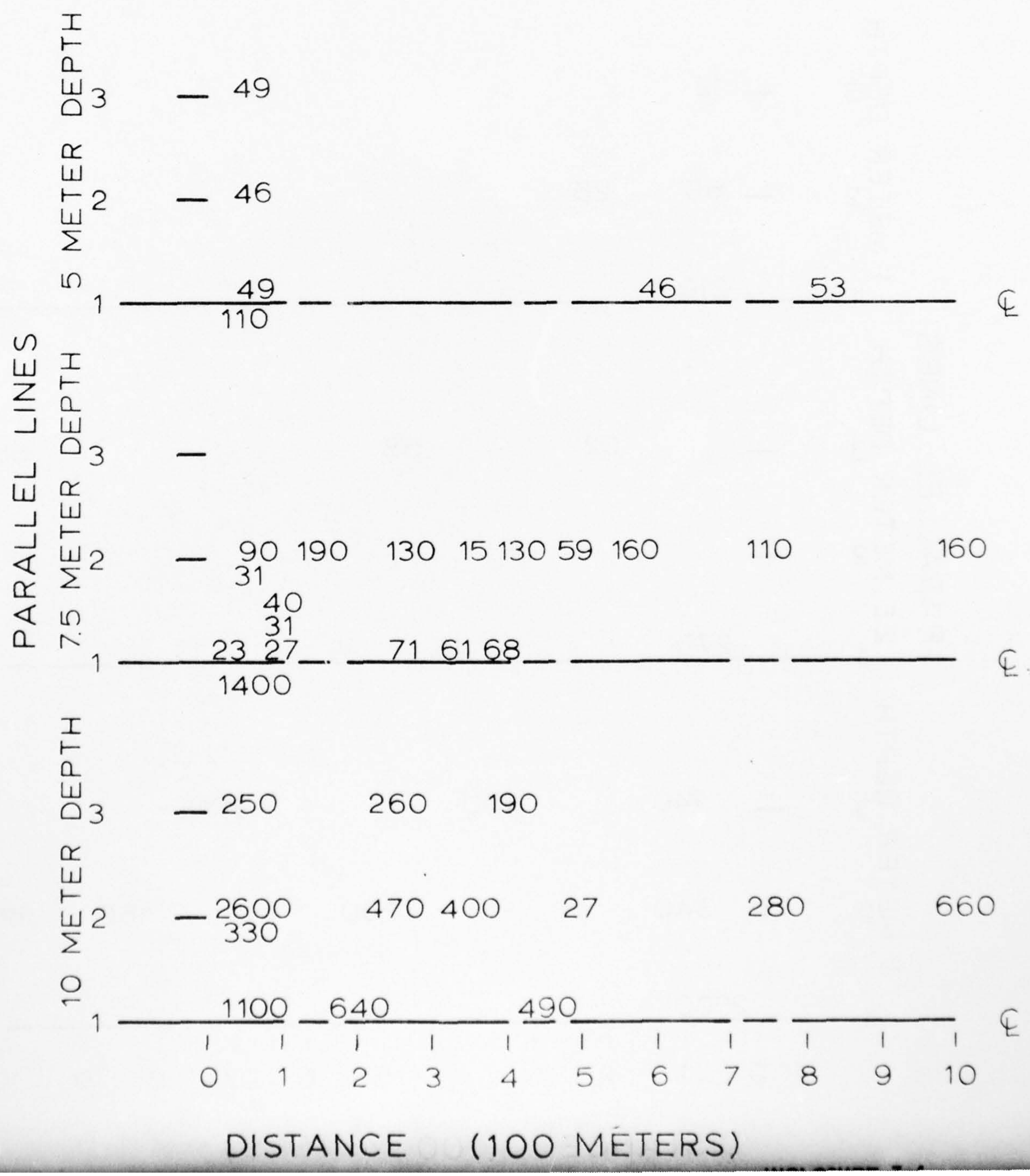
INCLOSURE 7

Suspended Solids Data
from Plume Definition Study

HOPPER DREDGE - MARE ISLAND STRAIT

SUSPENDED SOLIDS WITHOUT OVERFLOW Sep-Oct 74

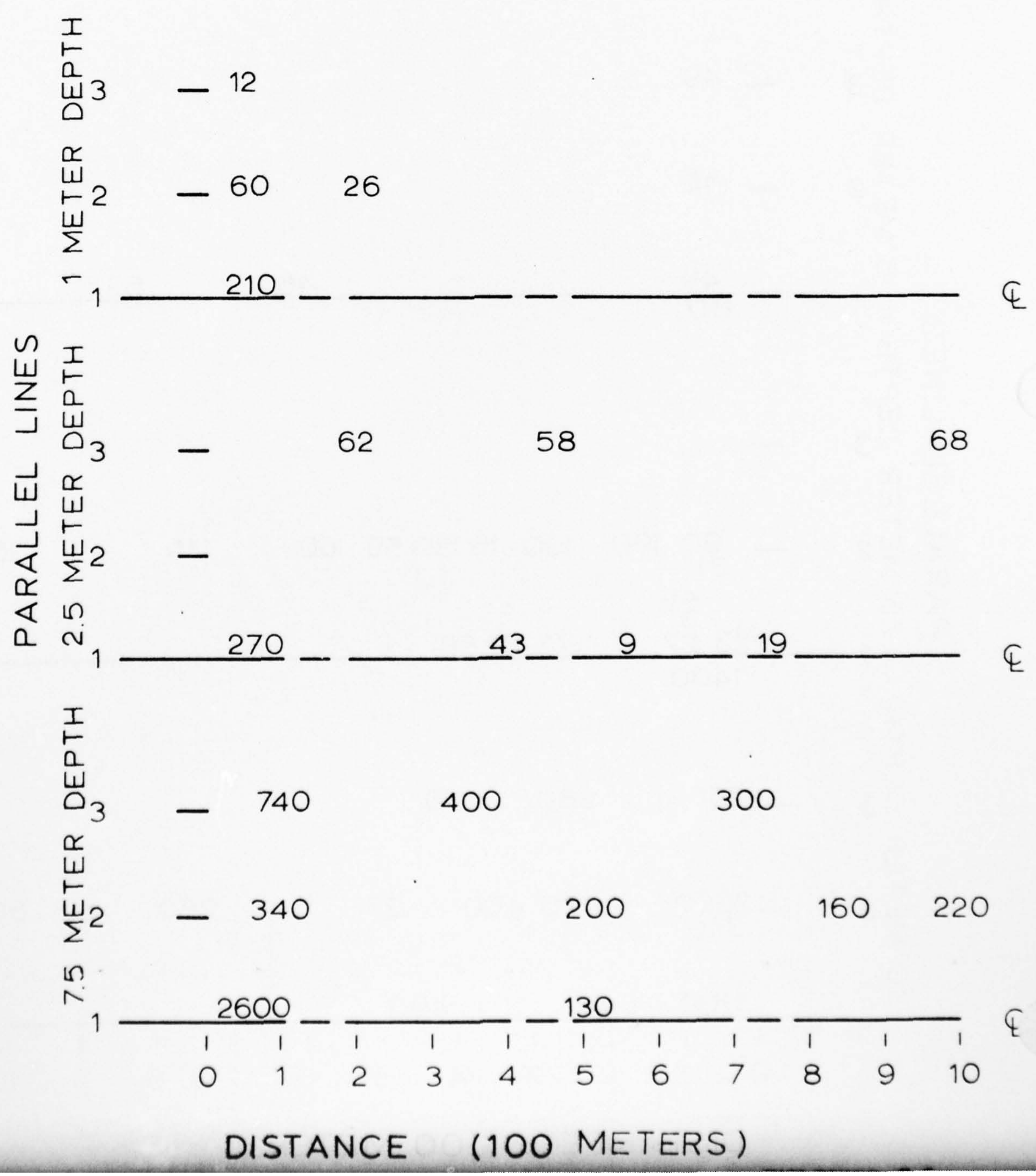
MILLIGRAMS / LITER



HOPPER DREDGE - MARE ISLAND STRAIT

SUSPENDED SOLIDS WITH OVERFLOW Sep - Oct 74

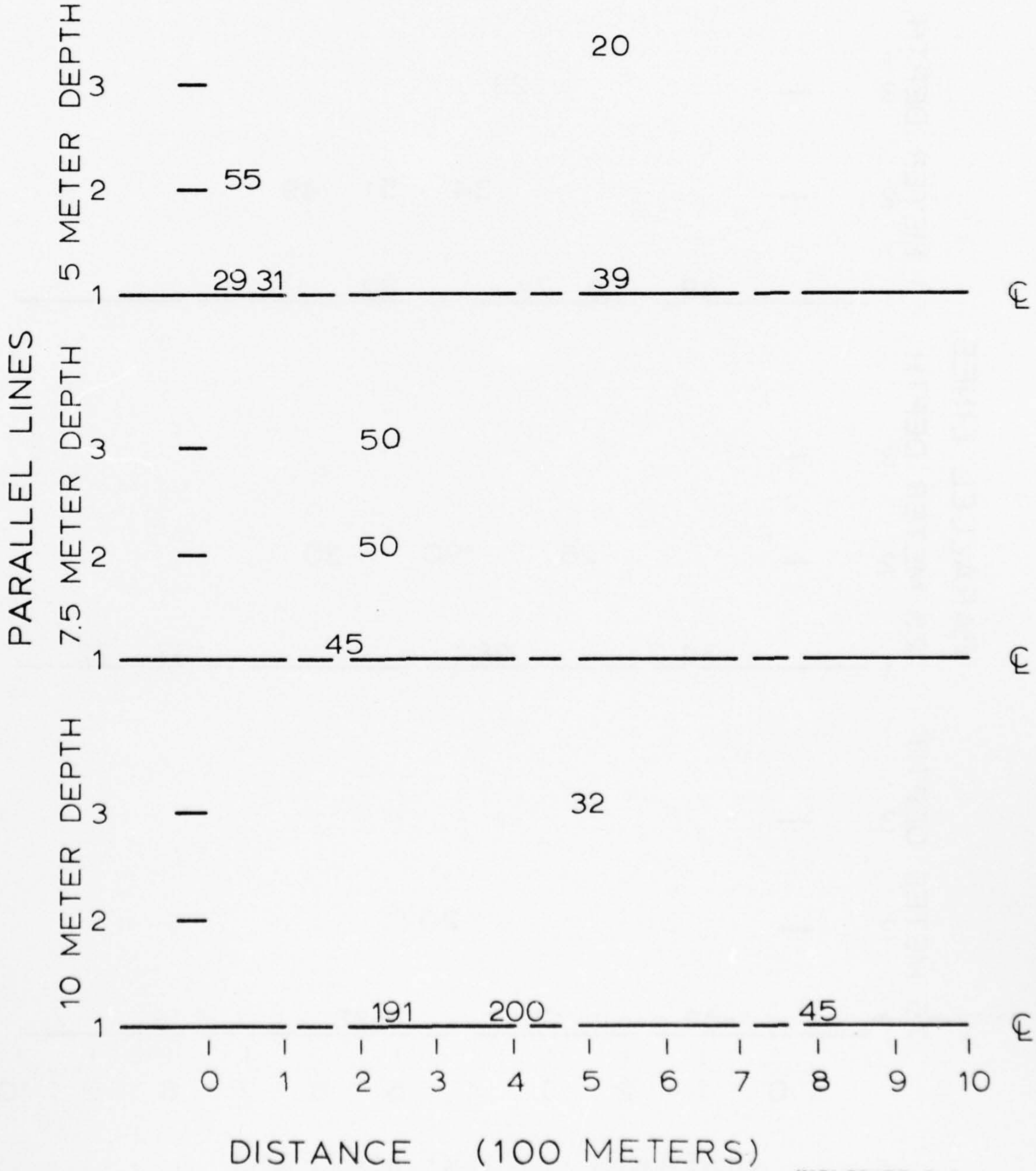
MILLIGRAMS / LITER



HOPPER DREDGE - RICHMOND HARBOR

SUSPENDED SOLIDS WITHOUT OVERFLOW Nov 74

MILLIGRAMS / LITER

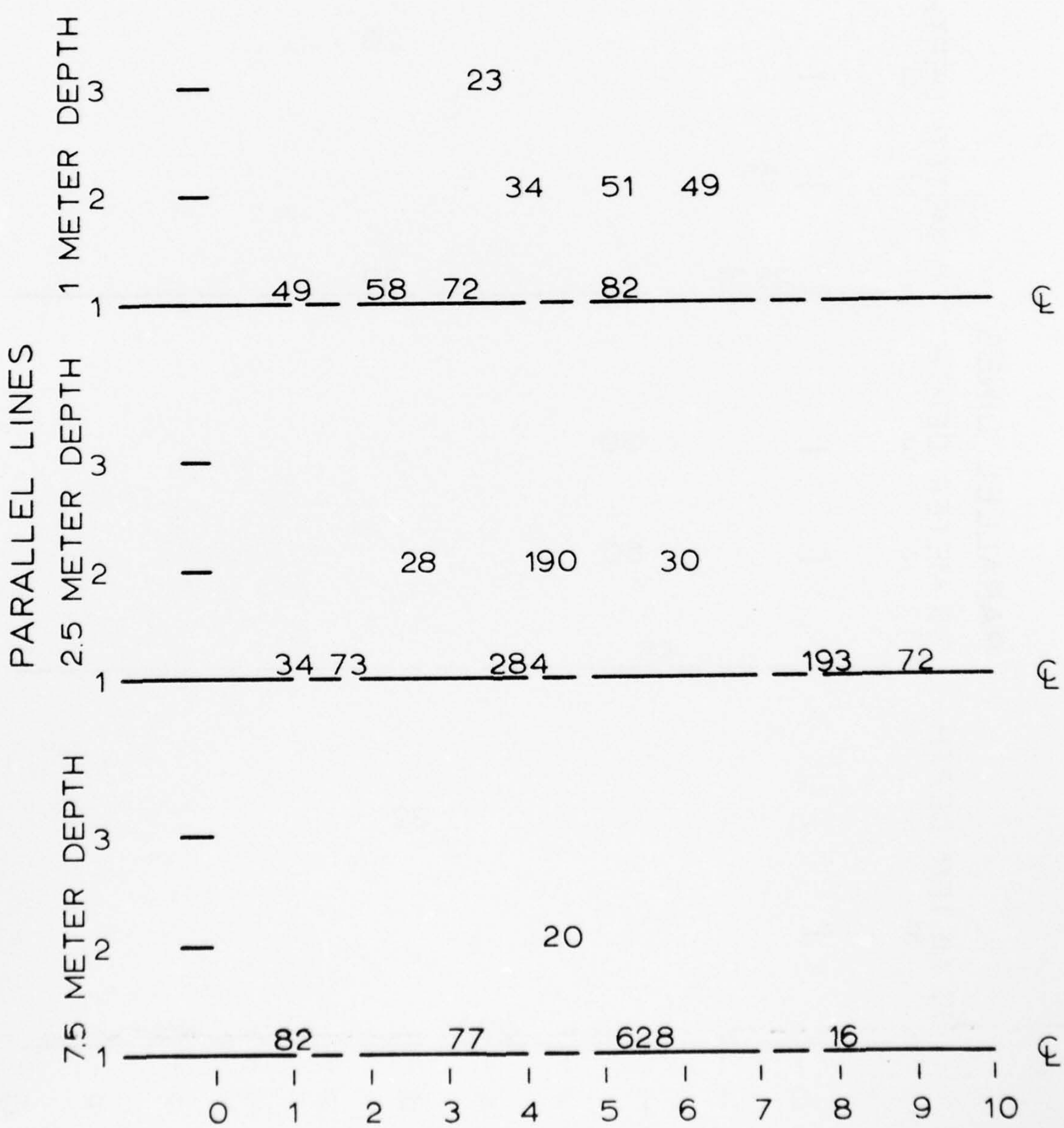


INCLOSURE 7-3

HOPPER DREDGE - RICHMOND HARBOR

SUSPENDED SOLIDS WITH OVERFLOW Nov 74

MILLIGRAMS / LITER



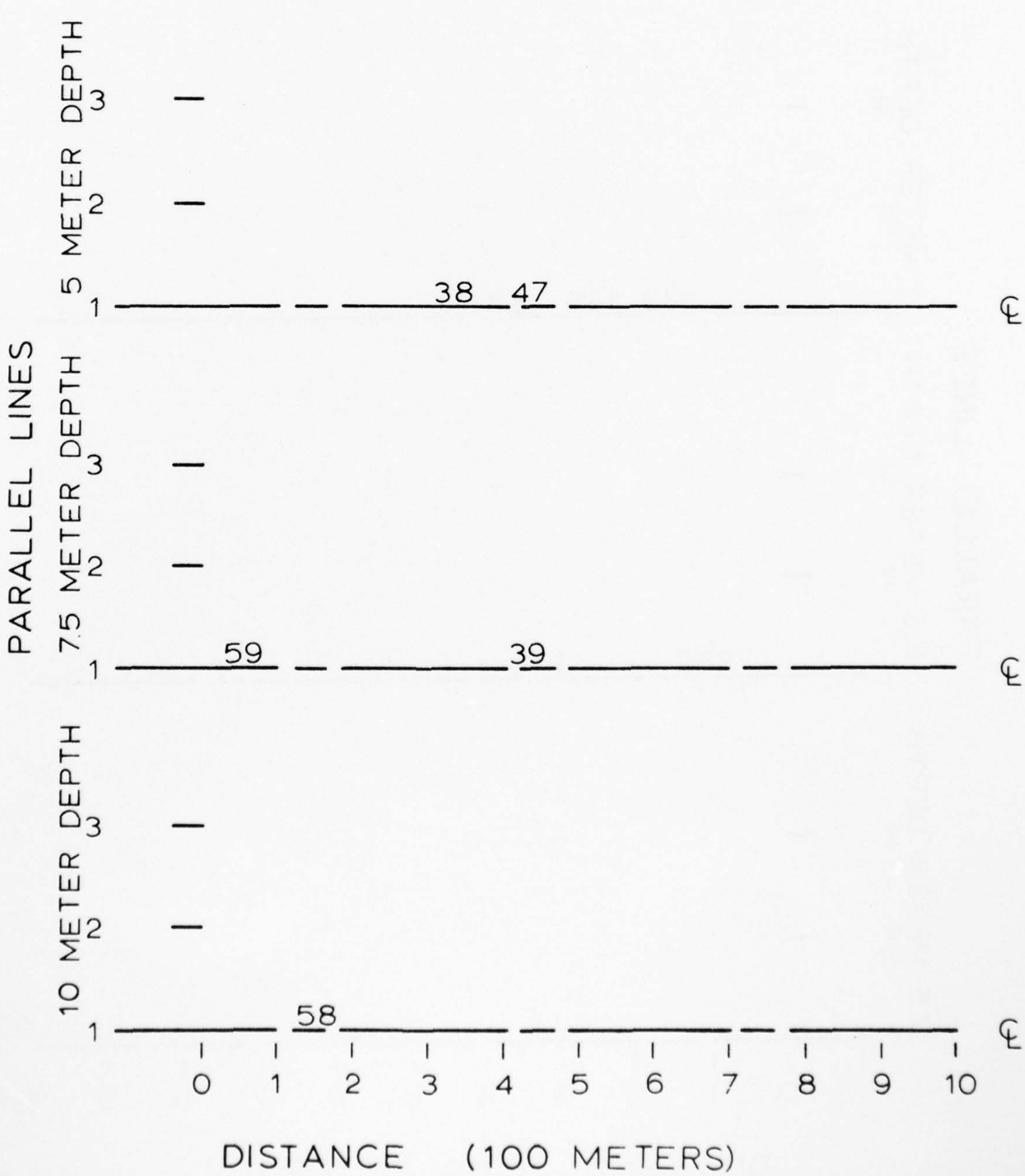
DISTANCE (100 METERS)

INCLOSURE 7-4

HOPPER DREDGE - ALAMEDA NAVAL AIR STATION

SUSPENDED SOLIDS WITHOUT OVERFLOW Dec 74

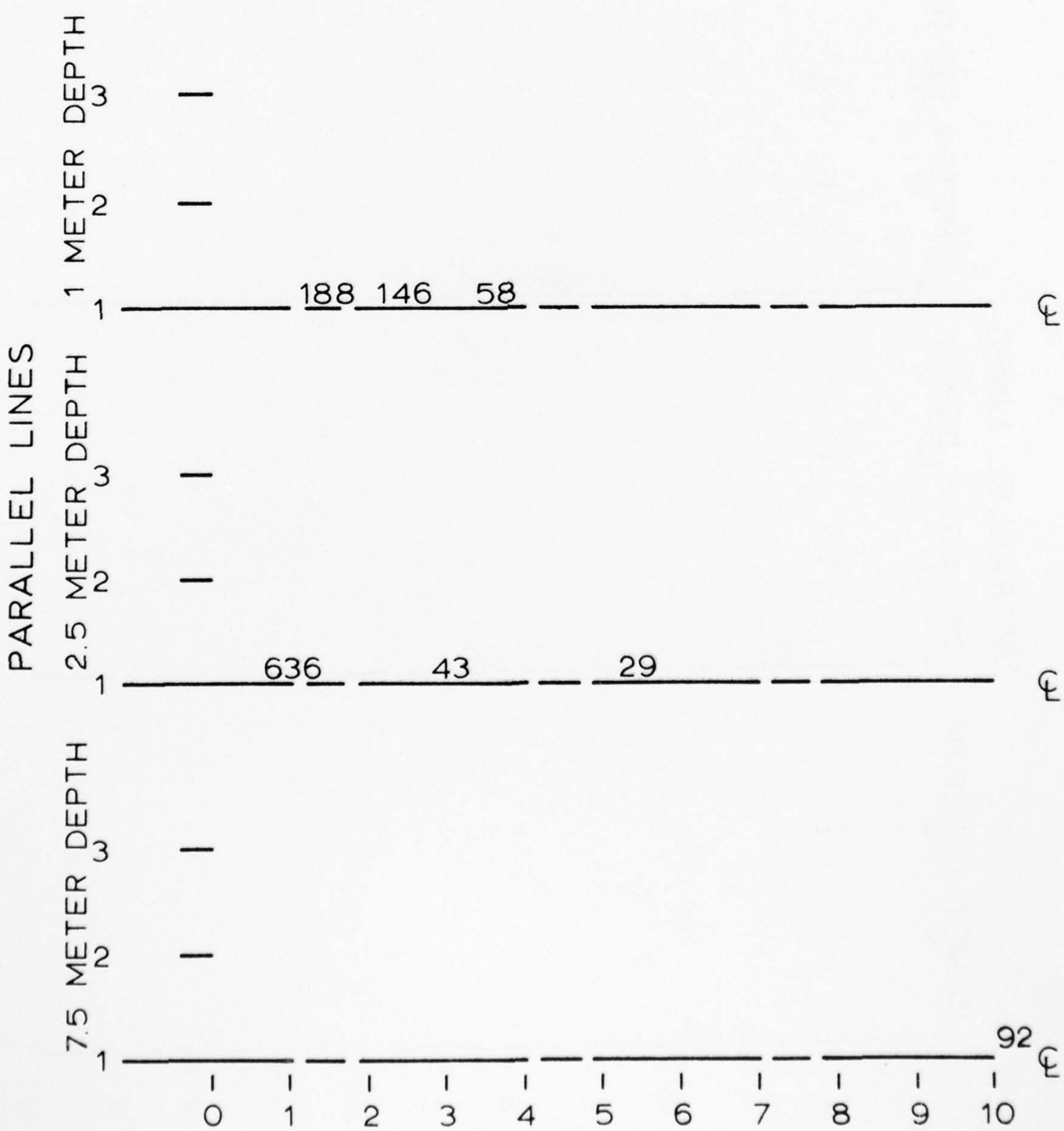
MILLIGRAMS / LITER



HOPPER DREDGE - ALAMEDA NAVAL AIR STATION

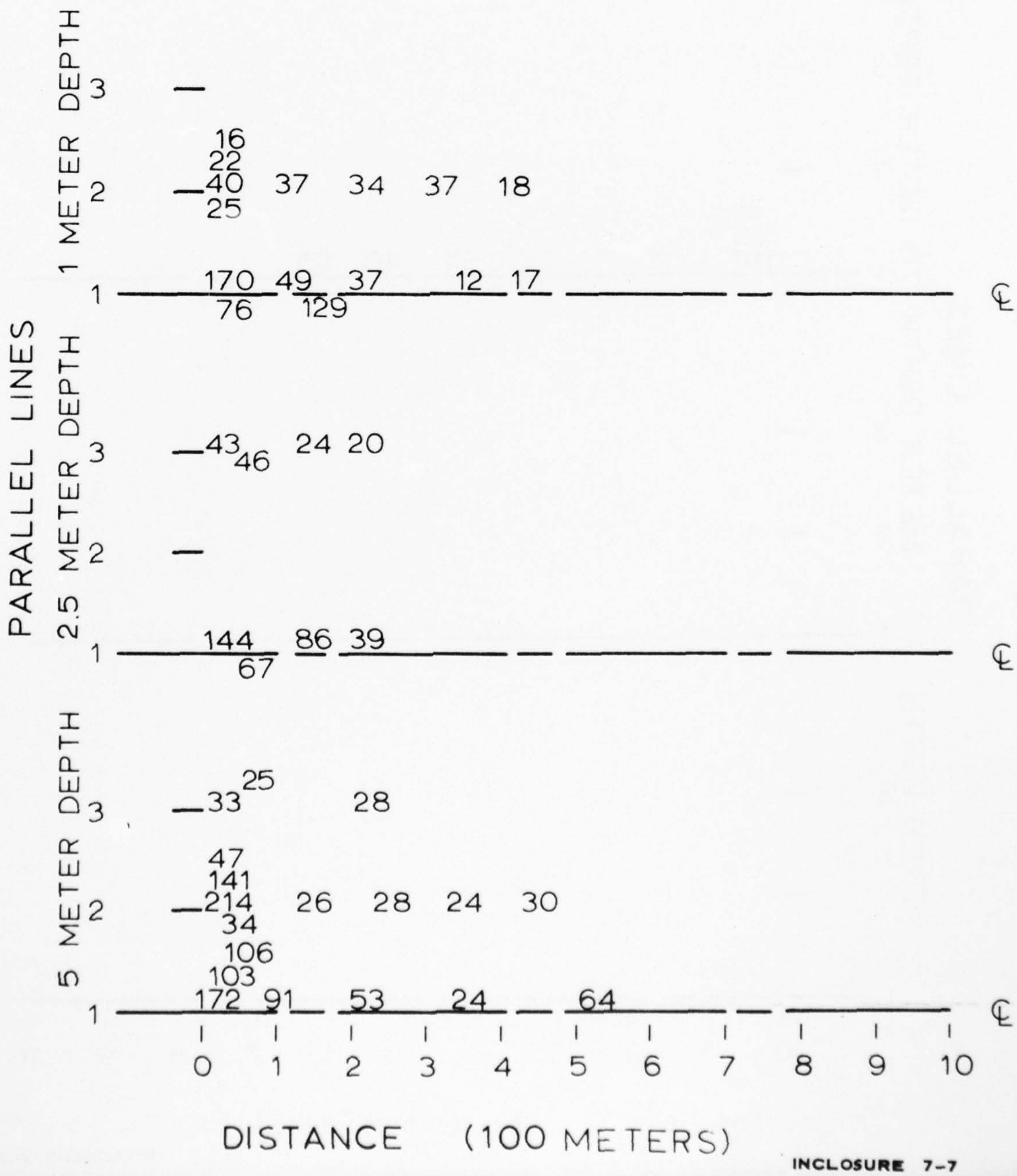
SUSPENDED SOLIDS WITH OVERFLOW Dec 74

MILLIGRAMS / LITER



CLAMSHELL DREDGE - ALAMEDA NAVAL AIR STATION

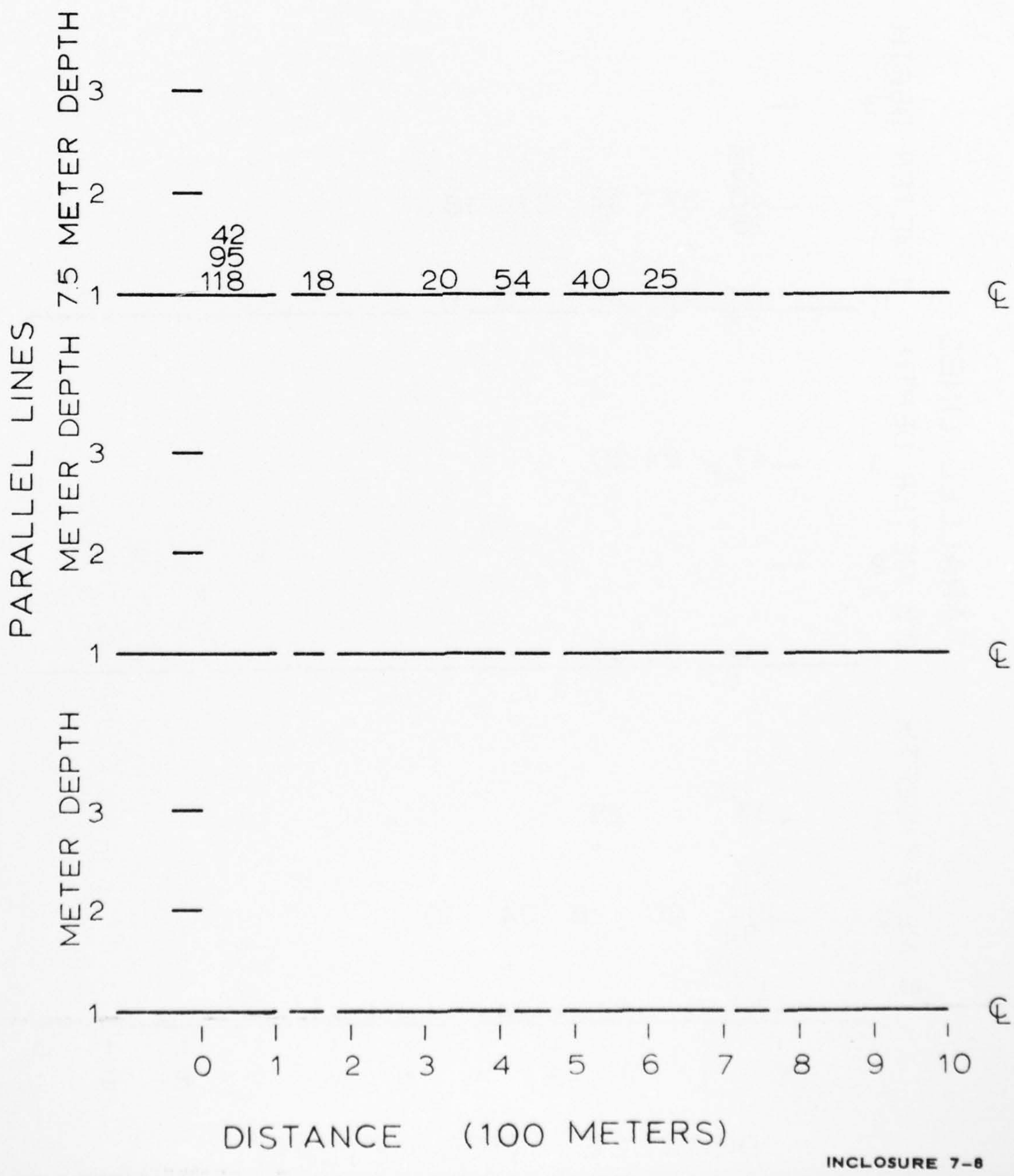
SUSPENDED SOLIDS (MILLIGRAMS / LITER) Jan 75



INCLOSURE 7-7

CLAMSHELL DREDGE - ALAMEDA NAVAL AIR STATION

SUSPENDED SOLIDS (MILLIGRAMS / LITER) Jan 75



INCLOSURE 7-8

INCLOSURE 8

Effects of Dredged Materials
on Dissolved Oxygen in Receiving
Water - March 1973
Contract No. DACW07-73-0051

EFFECTS OF DREDGED MATERIALS ON DISSOLVED OXYGEN IN RECEIVING WATER

A Report Prepared by
Brown and Caldwell for
U.S. Army Corps of Engineers

March 1973

Contract Number DACWO7-73-C-0051

AD-A038 310 CORPS OF ENGINEERS SAN FRANCISCO CALIF SAN FRANCISCO--ETC F/G 13/2
DREDGE DISPOSAL STUDY, SAN FRANCISCO BAY AND ESTUARY. APPENDIX --ETC(U)
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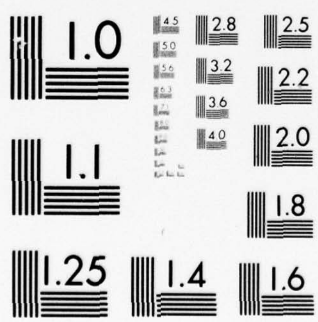


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

EFFECTS OF DREDGED MATERIALS
ON DISSOLVED OXYGEN IN
RECEIVING WATER

CONTENTS

EFFECTS OF DREDGED MATERIALS ON DISSOLVED OXYGEN IN RECEIVING WATER

Maintenance of deepwater shipping channels in San Francisco Bay and its various estuaries requires regular dredging. Disposal of the dredged material has for many years been accomplished by dumping at designated disposal sites. The ultimate fate of the material is not precisely known, but as disposal areas are all in scoured channels, natural currents move the wastes to areas of wide dispersion. Krone (1) and Gustafson (2) have pointed out that all sediment movement within San Francisco Bay attributable to dredging operations is only a minor fraction of net sediment movement brought about by winds, tidal currents, fresh water flows, and similar natural processes.

In recent years, concern has been expressed about possible detrimental effects of disposal of dredged material on benthic organisms in and near disposal sites, and consequently upon higher organisms in the bay ecosystem. More recently, additional concern has been focused on possible effects on the water itself as dredged sediments are released into it. Degradation of water quality would presumably have detrimental effects on planktonic and higher organisms.

A recent study (3) attempted to establish a cause and effect relationship between increased turbidity following release of dredged sediments and various effects on biota in the vicinity. As Gustafson has pointed out, errors of logic and method render the conclusions of that study open to considerable question. The same report (3) refers in passing to reduced levels of dissolved oxygen encountered where dredged sediments were released; reference is also made to some laboratory experiments that suggest that a significant depression in oxygen content could occur and persist for a significant period of time when dredged sediments are released into water above disposal sites.

In January 1973, the U.S. Army Corps of Engineers, San Francisco District, initiated the maintenance dredging of Mare Island Strait, which comprises the lower end of the Napa River, with discharge of the dredged material in a designated disposal area south of Mare Island in the westerly end of Carquinez Strait. The material comprises fine silts from the bay system and sediments and debris from the Napa River. Previous studies have shown that these sediments are somewhat polluted. Pollution sources include the urban drainage of the City of Vallejo and of Mare

Island Naval Shipyard, and industrial wastes which until recently were discharged without treatment from the shipyard. The tidal portion of the Napa River is quite eutrophic and has excessive algal blooms at times during the summer months. The sediments may contain organic debris from these blooms. The dredging program, undertaken in January and early February 1973, offered an opportunity to measure the effect of dredged material from a moderately polluted area upon dissolved oxygen in the receiving water during the disposal operation.

Authorization and Scope of Study

As a part of its broad scope of investigations on the effects of dredging on the environment, the Corps of Engineers, San Francisco District, engaged Brown and Caldwell, consulting engineers, to undertake this study. Under the agreement, contract number DACWO7-73-C-0051 dated 17 January 1973, the contractor provided services as follows:

1. Furnish professional and technical personnel, equipment, boats and other transport, and laboratory, computer, reproduction and necessary office services to determine the effects of dredged materials on dissolved oxygen.

2. Obtain core samples of sediments in disposal area and examine for redox potential.

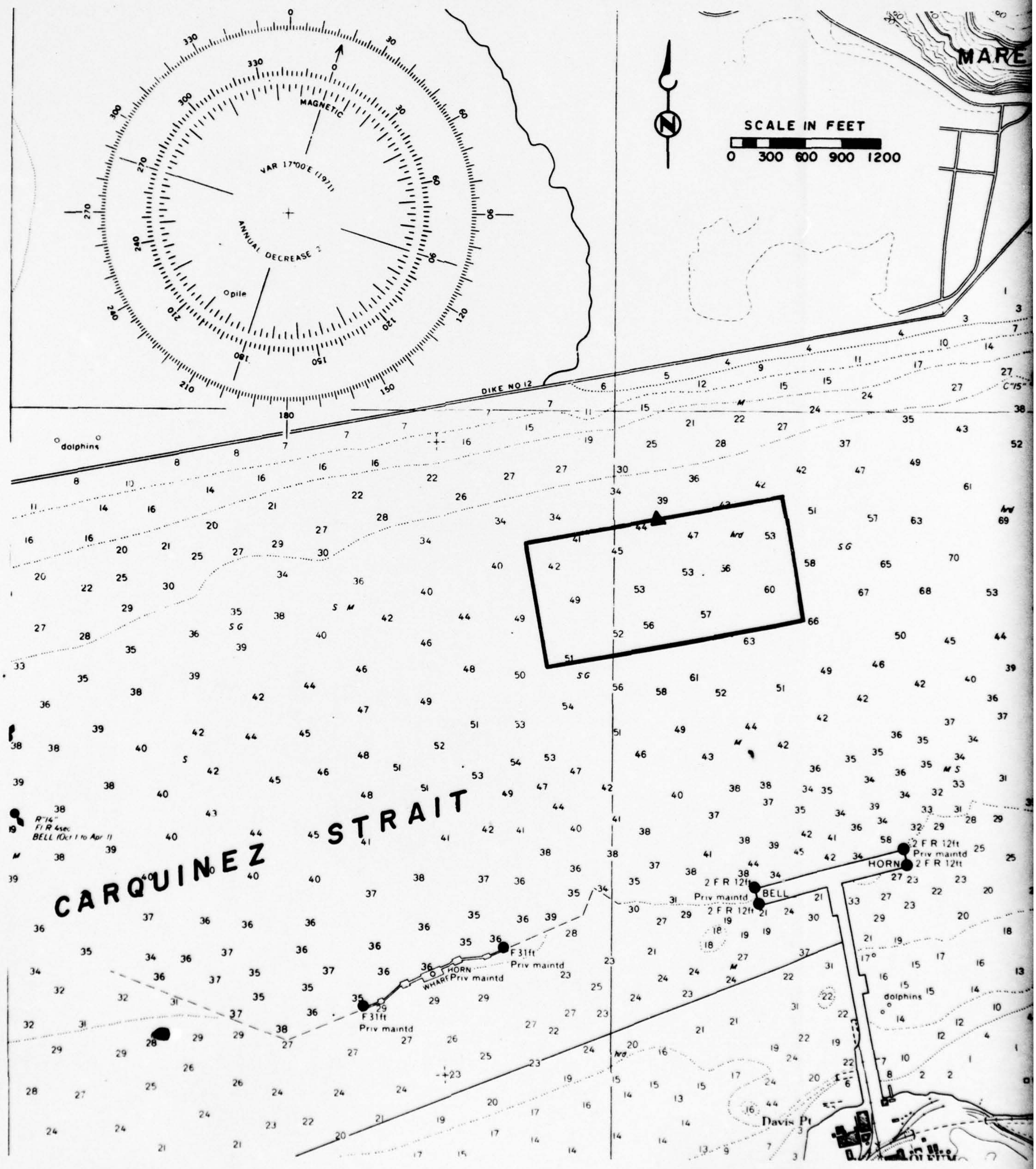
3. Sample dredged material before discharge and examine for physical and chemical characteristics.

4. Prepare written report describing procedures, presenting field data, and results of laboratory analyses, and discussing effects of dredge operations on dissolved oxygen.

The Corps of Engineers were to provide a marker buoy, an observer on one of the engineer's boats, and communications with the master of the dredge.

In scope, the study was laid out to cover an expected six discharges of dredged material on each of two days about one to two weeks apart. Subject to changes necessary to meet conditions as actually encountered, the field work each day was scheduled to include activities as follows:

1. From a vessel anchored adjacent to the marker buoy at frequent time intervals measure current velocity and direction at intervals of depth from surface to bottom; measure background temperature, conductance and dissolved oxygen likewise in profile. Record


MARE
SCALE IN FEET
0 300 600 900 1200
MAGNETIC
VAR 17°00'E (1971)
ANNUAL DECREASE 2'
pile
DIKE NO 12
dolphins
CARQUINEZ STRAIT
R "14"
Fl R 4sec
BELL (Oct 1 to Apr 1)
F 31ft
Priv maintd
HORN
WHARF Priv maintd
2 F R 12ft
Priv maintd
BELL
HORN
Davis Pt

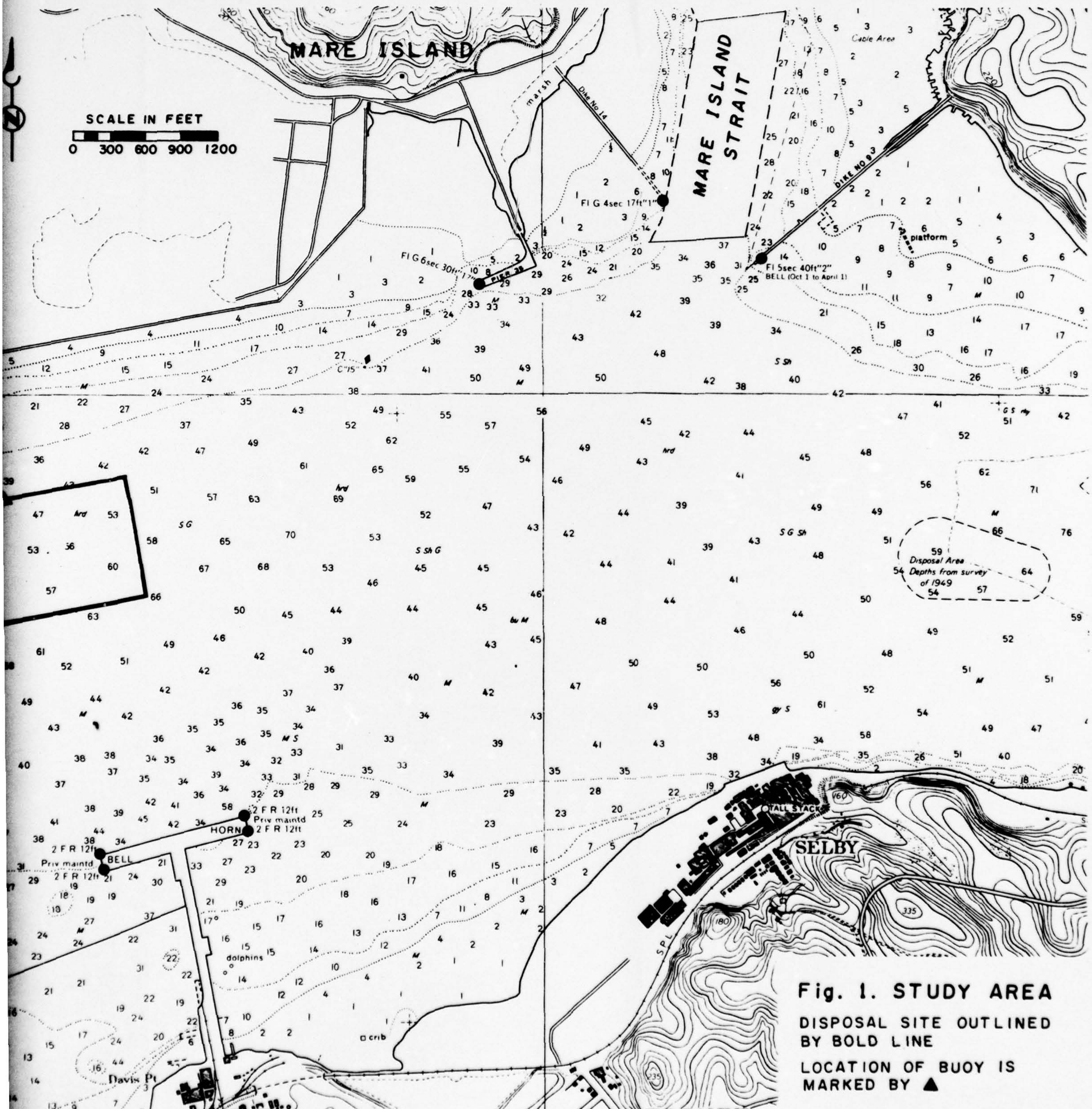


Fig. 1. STUDY AREA

DISPOSAL SITE OUTLINED BY BOLD LINE

LOCATION OF BUOY IS MARKED BY ▲

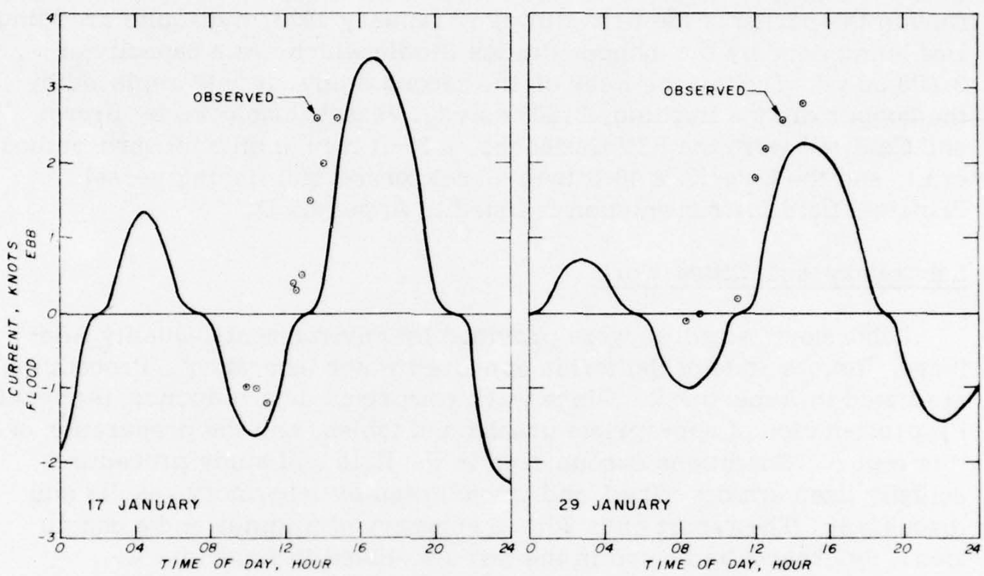


Fig. 2 Tidal currents at study site for each field trip. Observed points are surface currents. Datum for predicted currents: Davis Point, Carquinez Strait.

wind and other weather data. At slack water obtain sediment cores by divers for determination of redox potential and total sulfides.

2. With a second vessel, upon each discharge, move in behind the hopper dredge and drift in the water through which the dredged material dropped. Measure effects by profiling the water column for dissolved oxygen, temperature, conductivity, pH, and turbidity. Continue these measurements until dissolved oxygen rises.

3. Repeat measurements upon hopper discharge both under normal dredger operating procedures and under modified procedure to minimize change in dissolved oxygen.

4. Obtain samples of dredged material from the hopper of the dredge for laboratory analyses of grain size, redox potential, sulfides, and organic matter.

Field Work

The location of the dredged material disposal area and of the marker buoy in relation to Mare Island, Carquinez Strait, and Mare Island Strait

(Napa River) is shown on Fig. 1, a section of USC&GS Chart No. 5525. During the period of the first study, 17 January 1973, hydraulic dredging was being done by the hopper dredge Biddle which has a capacity of 3,000 cu yd. During the week of the second study, it was replaced by the hopper dredge Harding, 2,600 cu yd. Vessels employed by Brown and Caldwell were the R/V Camanche, a 25-ft twin engine inboard-outboard craft, and the Evie-K, a 40-ft twin diesel commercial fishing vessel. Principal field instrumentation is listed in Appendix D.

Laboratory and Office Work

Laboratory services were provided by Environmental Quality Analysts, Inc., a State of California approved water laboratory. Procedures are listed in Appendix E. Office work comprised data reduction (Appendix F), presentation of appropriate graphs and tables, and the preparation of this report. Conditions encountered in the field and study procedures actually used are described and are followed by laboratory results and discussion. The report ends with a summary of findings and a conclusion. References indicated in the test are listed in Appendix A.

Acknowledgments

We greatly appreciate the interest and assistance of the staff of the San Francisco District office in this study and of the masters of the dredges Biddle and Harding. In particular we thank Mr. John Sustar and Lt. Thomas Wakeman for their help in scheduling and coordinating the field work. Observers included Mr. Richard Whitsell and Mr. Richard Russell of the California Regional Water Quality Control Board, San Francisco Bay Region.

Table 1. Results of Analyses on Samples of Sediment from Dredge Harding, 29 January 1973

Sample	A	B	C
Total solids, percent wet wt	40	40	41
Volatile solids, mg/kg dry wt	85,000	84,000	85,000
Chemical oxygen demand, mg/kg dry wt	46,000	45,000	42,000
Total sulfides, S, mg/kg dry wt	14	90	150
Eh, volts	-0.47	-0.47	-0.47
pH	7.0	7.1	7.0

Samples A, B, and C are replicates; results are in excellent agreement except for sulfides. See also Table 8.

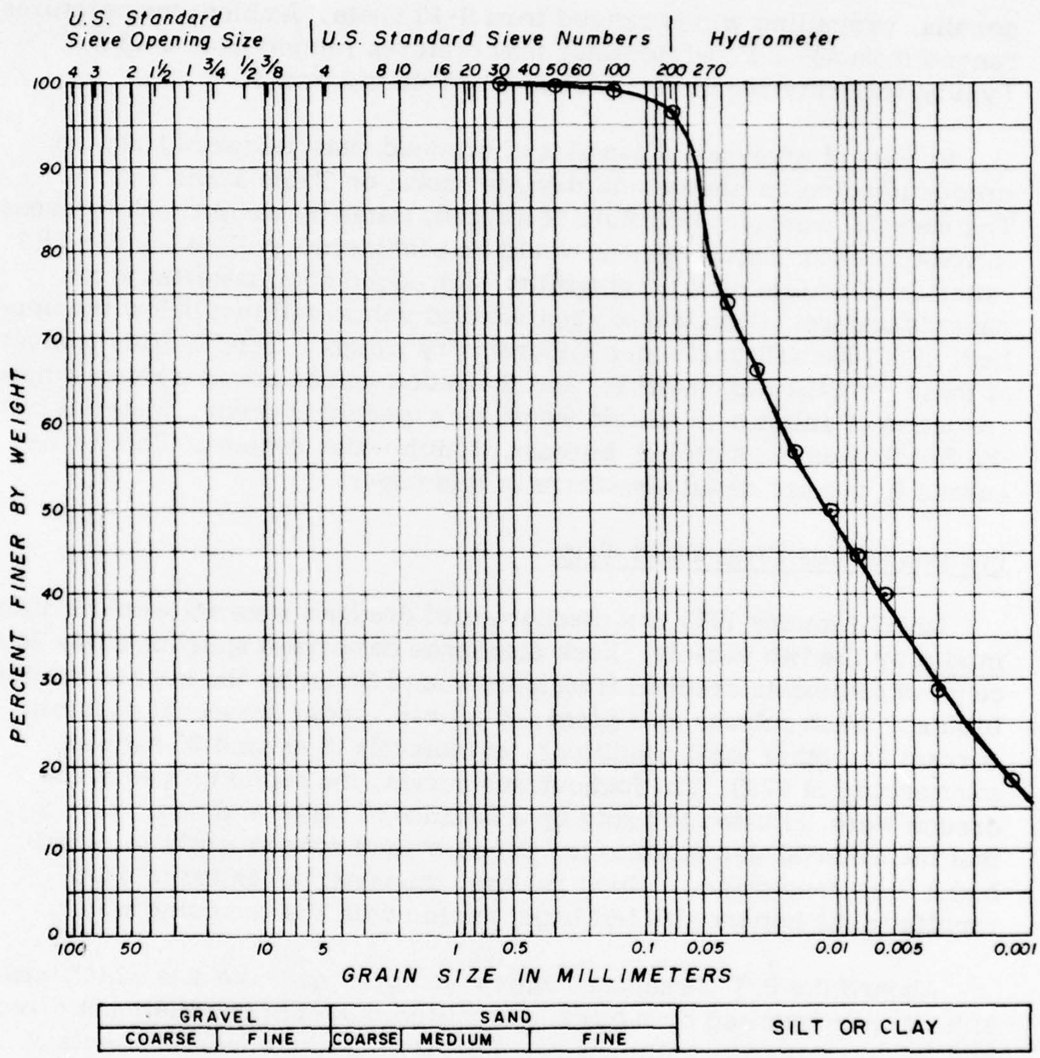


Fig. 3 Grain size distribution of sample from dredge Harding taken 29 January 1973.

FIELD INVESTIGATIONS

The field work was done on 17 January and 29 January 1973. For about one month prior to this period, excessively high precipitation had taken place. As a result, high outflow of fresh water was encountered, and background turbidity ranged from 200 to 400 JTU. Predicted and observed surface tidal current conditions are shown in Fig. 2 for each field trip. Weather for both days was overcast with occasional rain

squalls; prevailing winds ranged from 0-10 knots. Ambient temperatures ranged from 40-50 F, while water temperatures ranged from 8-10 C. Typical turbidity readings are shown in Tables 2 and 3.

Results of analyses of samples of dredged material taken from the dredge Harding on the second day are shown on Table 1 and Fig. 3. The material was approximately 60 percent water by weight. With respect to volatile solids, the sediment would be considered polluted under EPA criteria for determining acceptability of dredged spoil material to the nation's waters. Chemical oxygen demand values fall just below the upper limit of 50,000 milligrams per kilogram dry weight. Total sulfide content of these samples was variable, and the redox values are in a range where reduction of sulfates to sulfide would be expected to occur. Material from the Biddle was not sampled because of high water content. This is discussed in greater detail elsewhere in this paper.

Procedures for First Field Trip

On 17 January 1973 six discharges of dredged material were monitored in situ by the two vessels. Each discharge comprised approximately 3000 cu yd of sediments dredged from Mare Island Strait by the hopper dredge Biddle. Each release took place, of course, under somewhat different current and other local conditions, at intervals of around 80 minutes commencing at 0730. Throughout this series, the suction pipes of the dredge were adjusted to bring up a mixture of water and sediment, so that the material delivered to the hoppers (and subsequently released) had a fluid consistency. Upon release, the material tended to drop rapidly to the bottom with but little mixing with the receiving water.

Aboard the R/V Camanche, which anchored near the site which was to have been marked by a buoy, prevailing currents and their net direction were monitored continuously. Repeated discrete measurements of sensor-depth, temperature, conductivity, dissolved oxygen, and pH were taken by means of a multiple-probe unit with read-out on deck. Through communication with the dredge master, the release of dredged material was coordinated with the aim that the released material would be placed as near as possible to the anchored vessel. Safe navigation, however, largely prevented effective placement in this fashion.

Aboard the R/V Evie-K, a duplicate multiple-probe unit was used to monitor water quality. A falling stream turbidimeter supplied by a submersible pump was also aboard to monitor turbidity, as one possible means of locating the affected water column to be monitored. The initial plan of attack was to pull the Evie-K in behind the dredge immediately following the discharge of its contents; upon suitable indication of location in the water column affected by the release, the boat was stopped by reversing the propellers, engines were cut, and monitoring was begun.

Table 2. Turbidity Profile

Depth, ft	Turbidity, JTU
1	360
5	360
10	360
15	270
20	270
30	430

The samples were taken between releases near the buoy site at 0820 17 January.

Table 3. Surface Turbidity

Release No.	Turbidity, JTU
1	320
2	470
3	200
4	230
5	230
6	150

Samples were taken every five minutes following each release 17 January. There are no significant differences from the depth profile results shown in Table 2.

Table 4.
Examples of Salinity Profiles
17 January 1973

Time, hr	Depth, ft	Salinity, ppt
0830	0	3.1
	10	3.4
	15	3.7
	20	14
	30	1.8
1230	0	1.9
	10	1.9
	15	22
	20	3.8
	30	13
	39	15
1430	0	0.8
	10	1.4
	20	2.0
	32	2.3

Table 5.
Examples of Salinity Profiles
29 January 1973

Time, hr	Depth, ft	Salinity, ppt
0830	0	6.2
	5	7.8
	10	8.9
	15	9.1
	20	9.1
	25	14
1300	0	6.0
	10	7.7
	20	14
	30	19
	40	21
	48	20
1505	0	7.6
	10	10
	20	10
	30	12

Profiles taken in the morning, around noon, and early afternoon between monitoring runs are shown. ppt = parts per thousand

During the early part of the day when slack water was expected, numerous current reversals and water strata were encountered. Tables 4 and 5 show the extreme variations of salinity with depth frequently observed. Tables 6 and 7 list current direction and velocity measurements with respect to time and depth, and show that while a net current of 1-1.5 knots prevailed, changes in direction were significant.

Release of dredge material from the Biddle normally took place over a period of about two minutes while the dredge was underway, during which time the dredge covered a distance of approximately 200 yd. The duration of release can be observed as the dredge rises rapidly from the water; reference to bow markings can establish the release period closely. It is impossible, however, to observe the actual release as it takes place well below the surface. Surface plumes of turbid water behind the dredge are not caused by release of sediment from the bottom of the hoppers, but are caused by the discharge of water used to fill the hoppers to assist the release.

In the early afternoon, the first indication of any oxygen depression was observed when currents washed the dredge discharge almost directly beneath the anchored vessel, whose monitoring equipment was at that moment near the bottom. The effect was little more than a momentary depression of dissolved oxygen readings to a level of approximately 3 mg/l; a second such event was observed on the last run. On each of these monitoring attempts, release by the dredge was modified, so that discharge was as rapid as possible, the entire operation taking place in less than one minute.

Results of First Field Trip

The observed readings for the first days' field operations are listed in Appendix B, Table 1 through 18. The reduced data, which show no significant differences between background readings and discharge monitoring, are presented with the text, Fig. 4 and 5. The very small oxygen depressions noted are visible on the graphs, Fig. 4i and k.

It was concluded after this day's efforts, and after a review of the data, that the effects being sought were more ephemeral than had been supposed. As a consequence, modifications of procedure were made for the second run, in the hopes that these brief effects could be reliably observed.

Procedures for Second Field Trip

The slightly smaller hopper-dredge Harding (capacity 2600 cu yd) was operating in the same pattern as the Biddle had operated on the pre-

Table 6. Current Profile During Release at Flood Tide
17 January 1973

Time, hr	Depth, ft	Current: Direction, degrees from true north	Current: Velocity, knots
0955	38	110	0.7
0959	30	120	1.5
1005	25	120	1.5
1010	20	110	1.2
1011	15	120	1.0
1015	10	110	1.5
1020	5	110	1.0
1022	0	100	1.0
1025	0	80	1.0
1027	5	100	1.5
1030	10	100	1.5
1033	Release		
1034	15	120	1.5
1035	20	120	1.0
1036	25	110	1.5
1037	30	110	1.5
1039	38	110	1.5
1044	30	120	1.0
1046	25	90	1.0
1049	20	100	1.2
1053	15	100	1.2
1054	10	90	1.2
1056	5	90	1.4
1058	0	80	1.2

The table covers a period of about one hr and shows several changes in current direction and velocity. The bottom was 38 ft from surface during this time.

vious field trip. Additionally, the buoy had been placed to which the R/V Camanche tied up. The somewhat smaller size of the Harding allowed greater maneuverability and consequent more precise placement of released material.

Weather conditions at the site were similar to the first field trip, but predicted tidal currents were not as extreme (see Fig. 2). Salt wedges and current anomalies were again observed at the site and background turbidity remained high.

Table 7.
Current at Bottom
During Releases at High Tide
29 January 1973

Time, hr	Current	
	Direction, degrees from true north	Velocity, knots
0837	120	0.2
0838	Release	
0839	120	0.2
0839:45	50	2.0
0840	120	0.8
0841	100	0.8
0842	140	0.5
0843	120	0.8
0922	120	0.8
0923	150	0.6
0924	Release	
0924:30	60	1.5
0925	120	0.5
0925:15	140	0.8
0925:30	100	0.2
0930	140	0.6
0931	120	0.8

Surface current was 0.1 knot. Note direction and velocity changes of considerable magnitude following releases. Depth was 43 ft.

In view of previous findings, it was decided that monitoring equipment should be left near the bottom before, during, and well after the time of release by the dredge, in order to capture the transient effects noted earlier. Fewer profiles were taken on this trip and more readings at constant depth were obtained. Since attempts to monitor a given body of water had been found virtually impossible, advantage was taken of prevailing currents, by placing the research vessels in positions such that the released material would be moved beneath them and into the location of sensing apparatus. As currents increased in the afternoon, this resulted in both vessels being tied up to the buoy with about 50 ft between them.

Results of Second Field Trip

A brief oxygen depression was observed by both monitoring units for a total of six times. In no case was the effect longer than 3 to 4 minutes in duration. Attempts to correlate the dissolved oxygen depression with turbidity measurements failed for at least two reasons: (1) the depth pump for the turbidimeter could not occupy the same space as the Martek probe equipment; and (2) the response-time of the turbidimeter was too slow to be able to register the brief passage of small amounts of more turbid water.

Rapid changes were observed in current meter readings following releases which took place close to the buoy. Fig. 13 depicts this turbulence following the first release, while the current meter was near the bottom.

The observed readings for the second days' field operations are listed in Appendix C, Tables 1 through 20. The reduced data are shown

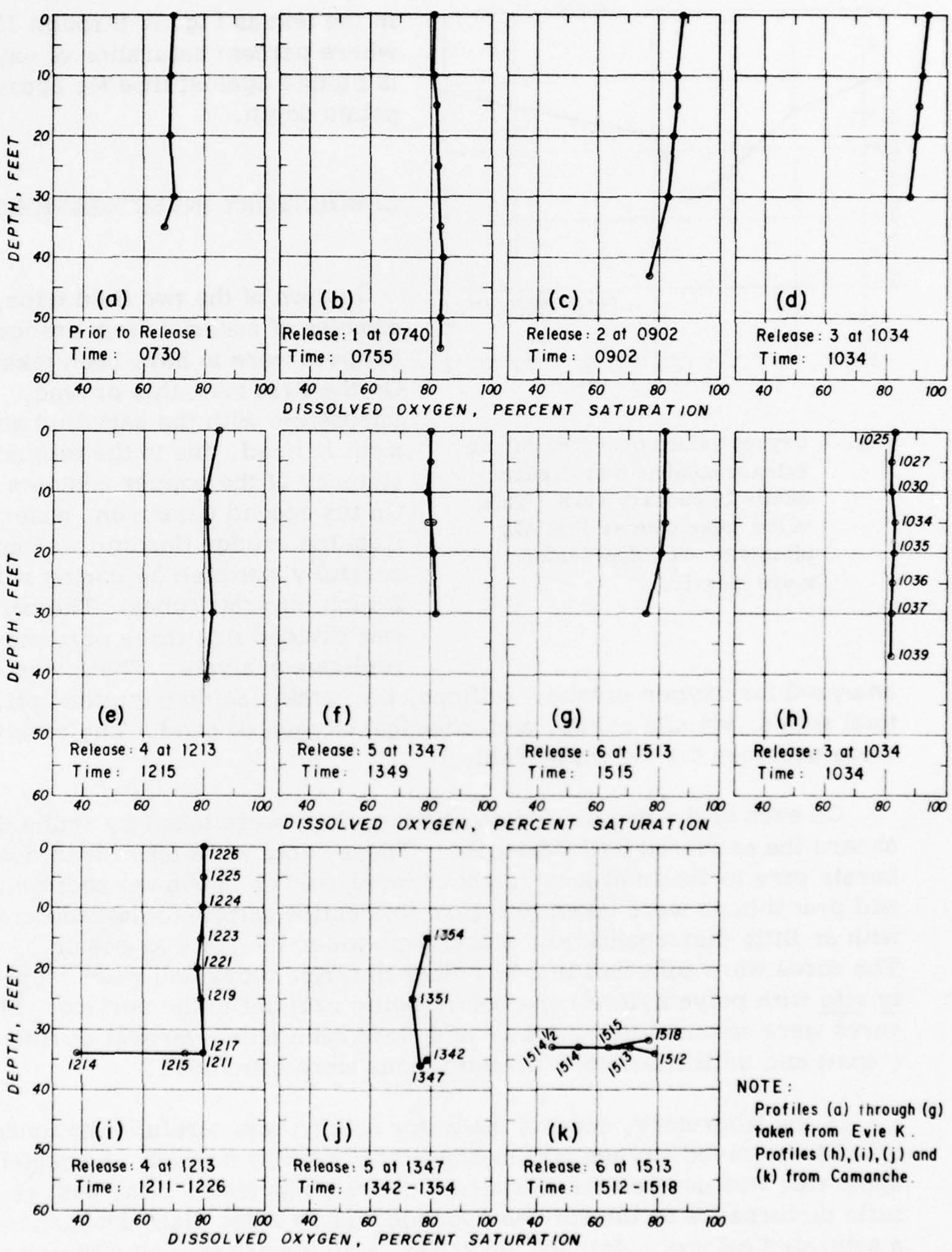


Fig. 4. Oxygen values observed during releases by dredge Biddle 17 January 1973.

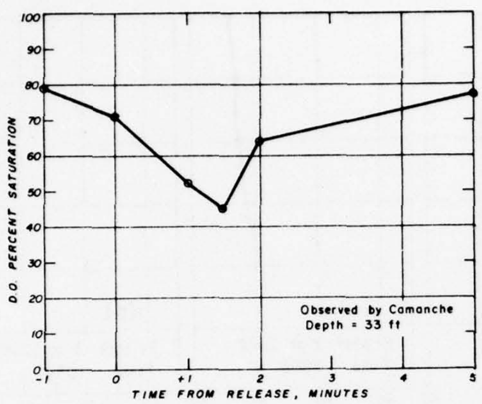


Fig. 5 Oxygen values observed during release number 6 by dredge Biddle 17 January 1973. This is the same data as Fig. 4k, plotted to show depression more clearly.

in the text as Fig. 6 through 12 where percent saturation of oxygen is plotted against time for appropriate depth.

LABORATORY INVESTIGATIONS

On each of the two field trips, samples of material from dredge hoppers were to have been taken. On the first run, this proved impossible with the sampling equipment at hand, due to the thin consistency of the hopper contents. On the second days' run, material from the dredge Harding was successfully sampled by coring with 2-inch butyrate tubes. The core was divided into three portions for replicate analysis. These were analyzed for oxygen uptake, sulfides, Eh, grainsize distribution, pH, total total solids, volatile solids, and chemical oxygen demand. The results of these analyses are shown in Table 1.

On each of the two field trips, bottom cores were taken by scuba divers aboard the anchored R/V Camanche. These cores were taken with deliberate care to obtain at least a foot of water column above the sediment, and precautions were taken to return this entire sample to the laboratory with as little disturbance to the sediment-water interface as possible. The cores were collected in 3-in. clear butyrate tubes and were capped in situ with polyethylene caps before being brought to the surface. The cores were retained in the tubes and were maintained vertical during transit and until laboratory investigations were concluded.

In the laboratory, some of the water column was carefully siphoned off and dissolved oxygen was measured by Winkler method. A special apparatus was devised for measuring the redox potential, Eh, with as little disturbance to the core as possible, using three platinum electrodes, a saturated calomel reference electrode, a pH electrode, and a thermometer (Fig. 15,16). Measurements of Eh, pH and temperature were taken at the liquid-solid interface, and at various depths as the probe cluster was moved down through the sediment. The butyrate plastic tube which contained the core was cut away as the measurements progressed, and sediment was removed as necessary; eventually, the entire core was composited and further analyses made on the composite.

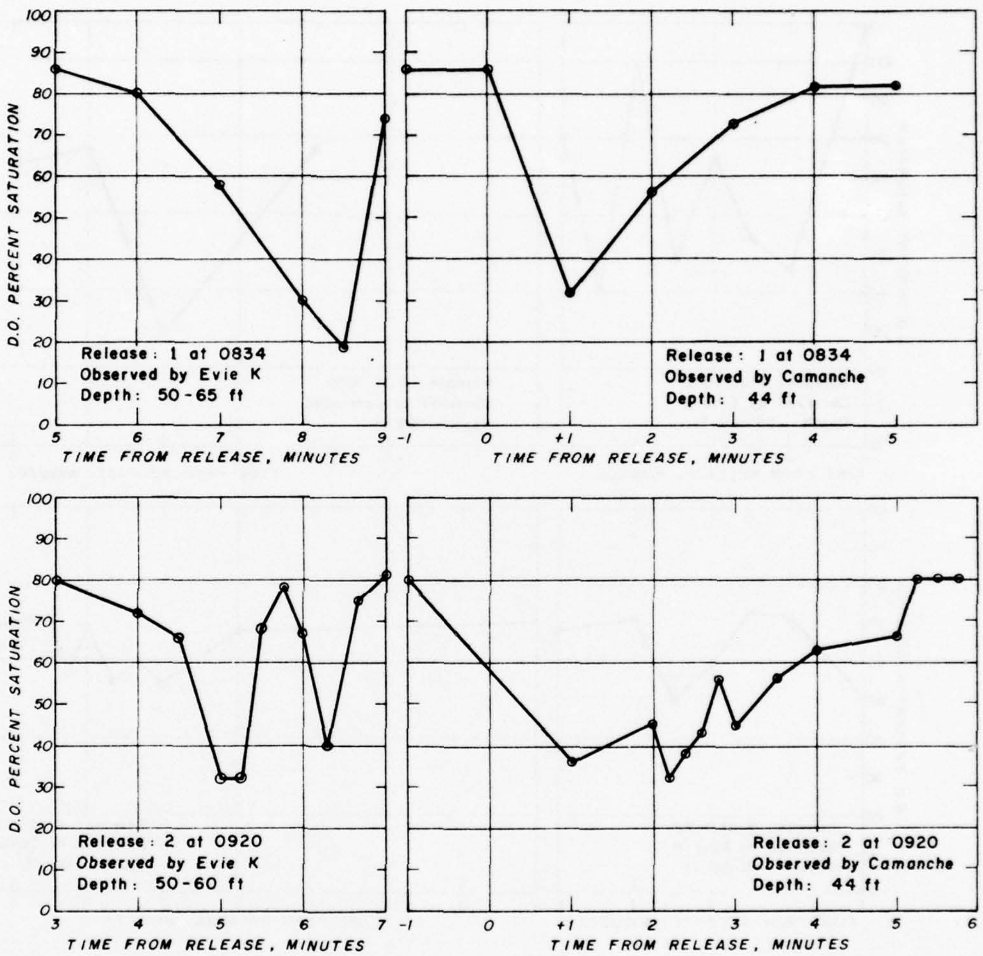


Fig. 6 Oxygen values observed during first and second releases from dredge Harding 29 January 1973.

DISCUSSION

At least two major phenomena can influence the effect (if any) on dissolved oxygen upon the release of dredged sediments into bay water. First, the material can have a true oxygen demand, such that by chemical reaction, oxygen may be consumed. A second factor which can influence the apparent dissolved oxygen in the receiving water is simple dilution. Normally, one would expect the dredged material to contain

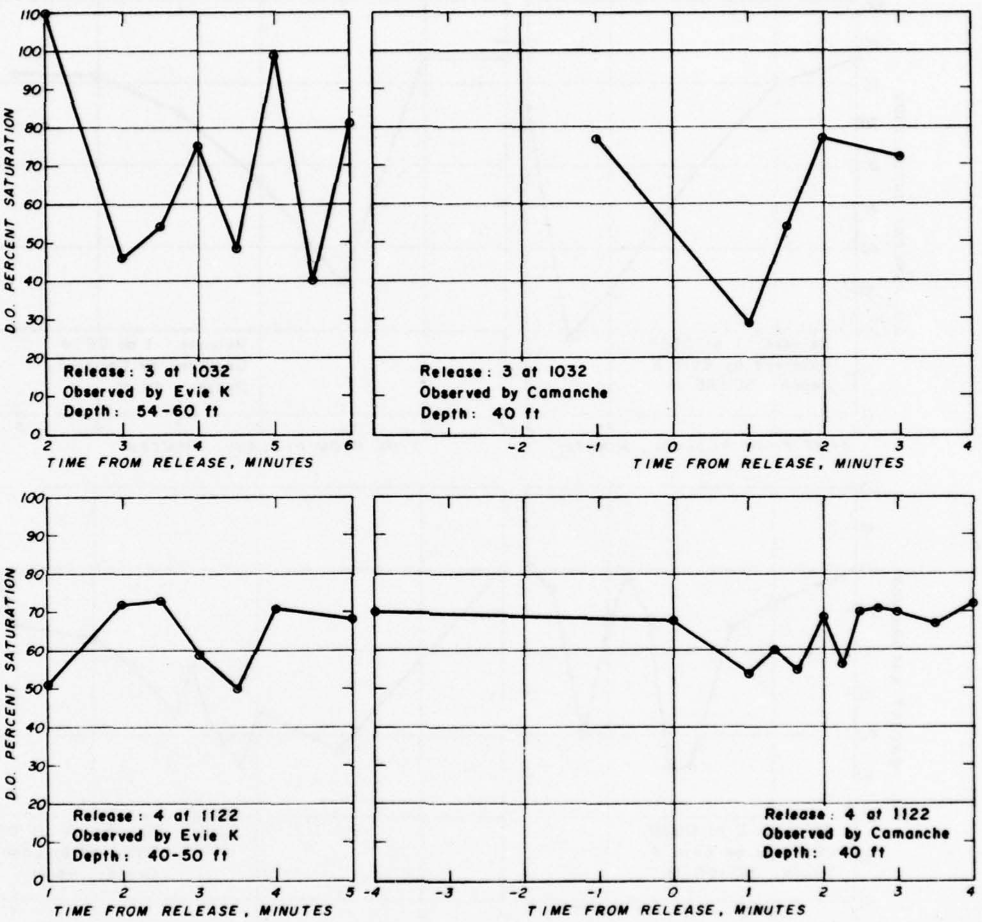


Fig. 7 Oxygen values observed during third and fourth releases from dredge Harding 29 January 1973.

little oxygen, and as this material mixes with the receiving water, some depression would be expected by dilution of the oxygenated water by the anoxic sediment.

Some predictions of the possible behaviour of dredged sediment release might be possible on the basis of chemical composition. Most notably, sulfides are known, under proper circumstances, to exert a rapid oxygen demand. To do so, sulfur must exist as free HS^- or H_2S, a condition which frequently occurs both in polluted bottom sediments and those of normal organic content. Organic carbon also exerts an oxygen demand, but requires the agency of organisms to mediate the process; hence the demand exerted by carbon would normally be expected

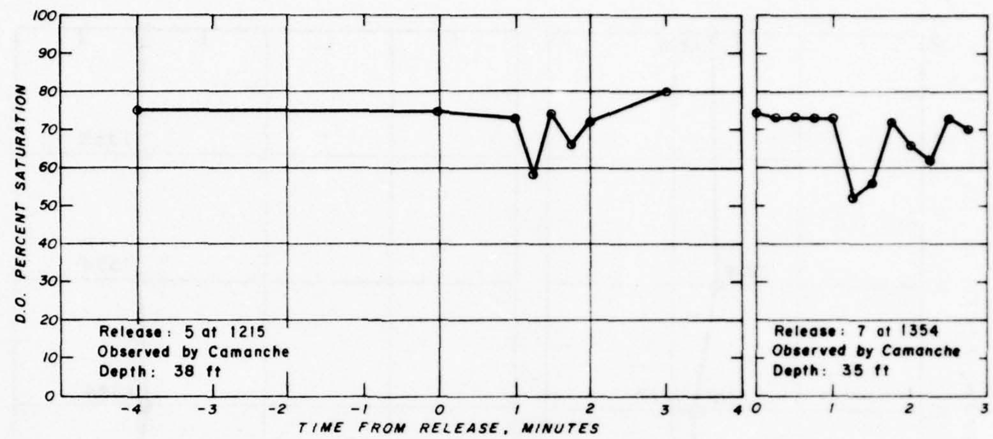


Fig. 8 Oxygen values observed by R/V Camanche during fifth and seventh releases by dredge Harding 29 January 1973.

to take place slowly, and under conditions of dredge release would probably not exert an observable demand.

On the first day's trip, as noted, the material which reached the hoppers was very fluid in consistency; the physical design of the transport channels for the dredge pump discharge is also such that considerable turbulence, with violent air-entrainment, takes place. Thus, the released material had only shortly before been diluted and vigorously aerated, and the immediate dissolved oxygen demand would thus have been partially satisfied.

Field Work

The field experience developed in this study indicated that only very transient oxygen depressions occurred following each release of dredged material. Because of the brevity of this phenomenon, the different positions occupied by the boats relative to the dump release position, and the vertical profile measurements, it is apparent that the occurrence did not take place over a wide area. During measurements on the second day, the two measuring systems were physically separated by about 50 ft, and each registered the phenomenon, but usually not quite simultaneously. The fleeting nature of the event made timing difficult, but the impression gained by all present supports the hypothesis that as the bulk of the released material reached the bottom, the localized disturbance there resulted in a "front" or "boil" which was monitored by the submerged sensors. This mass of water, containing a mixture of released material and briefly disturbed sediment from the existing bottom obviously con-

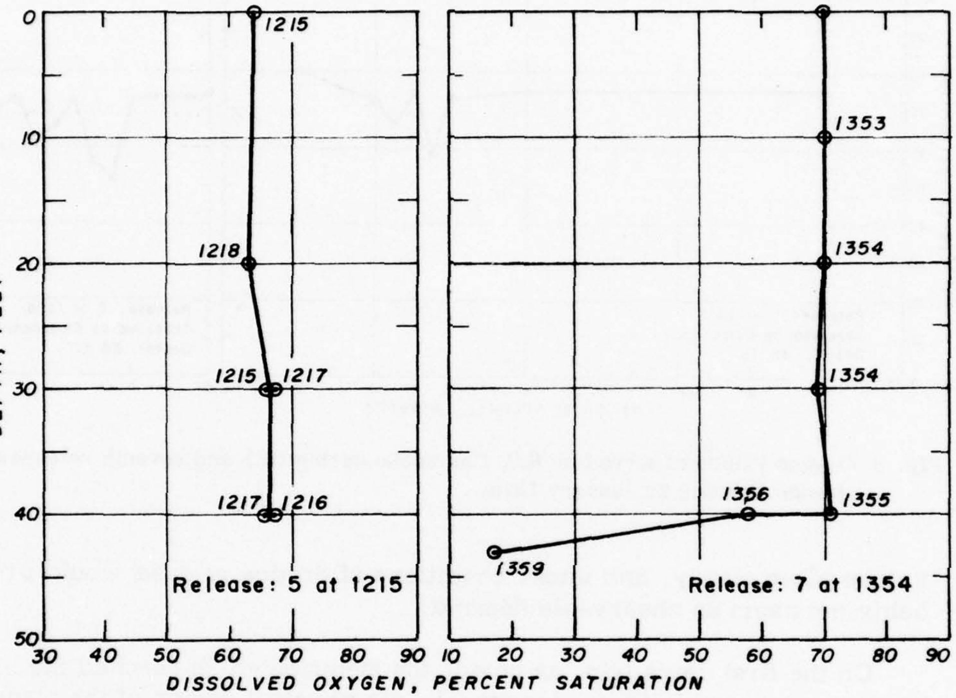


Fig. 9 Oxygen values observed by R/V Evie-K during fifth and seventh releases by dredge Harding 29 January 1973.

tained slightly less oxygen than the surrounding water mass, through the operation we feel, of both of the phenomena previously described which bear on the oxygen content. Observed current velocities were sufficient to promote rapid mixing of this small quantity of lower-oxygen water with the surrounding body of water, contributing to the brevity of the effect.

Laboratory Work

The two cores obtained on the two field trips differed in some details. The first core appeared to consist entirely of older sediments, uniformly black in color and with little stratification; there was not evidence to indicate that any part of the core consisted of recently deposited sediments from disposal operations. Fig. 14 shows Eh values obtained plotted against sensor penetration into the sediment. It was found that polarity reversal occurred essentially immediately below the sediment-water interface, and that reducing conditions prevail throughout the core, approaching maximum at 10 cm or less.

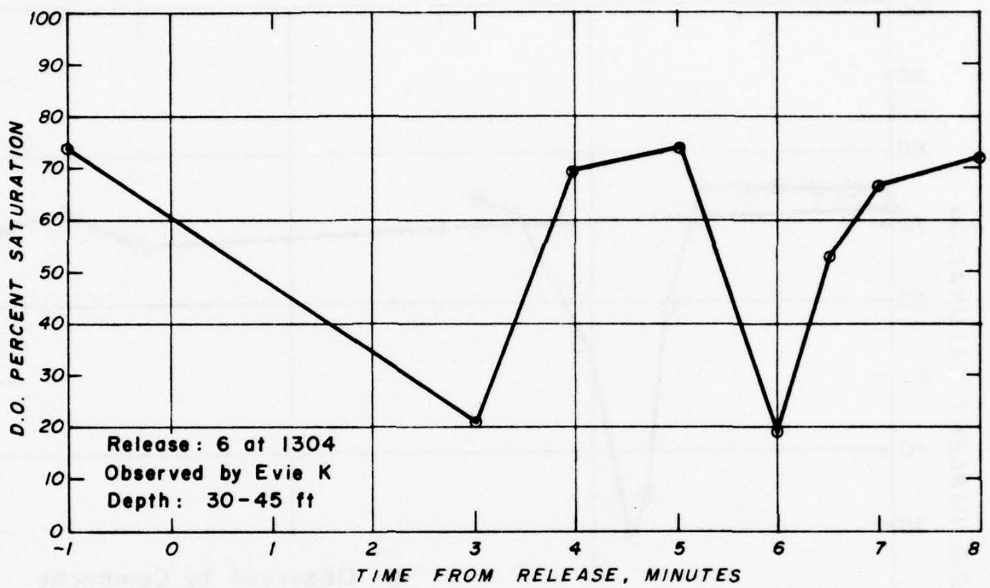


Fig. 10 Oxygen values observed by R/V Evie-K during sixth release from dredge Harding 29 January 1973.

The second core differed from the first in that the upper 20-22 cm was clearly a mixture of old deposits mixed loosely with fresh orange-colored deposits. As such, this portion of the core probably reflects more closely the materials suspended above it, a mixture of recently deposited silt washed into the bay by high runoff with older resuspended mud and (possibly) recently deposited dredged sediments. Millivolt readings obtained in this non-homogeneous mixture were very variable, and agreement among the three electrodes was poor, but Eh values obtained were uniformly negative in sign, once the electrodes had penetrated the actual interface. At a depth of 22 cm, the core became much more dense and uniform in consistency and appearance. Correspondingly, agreement between the three electrodes became significantly better at this point.

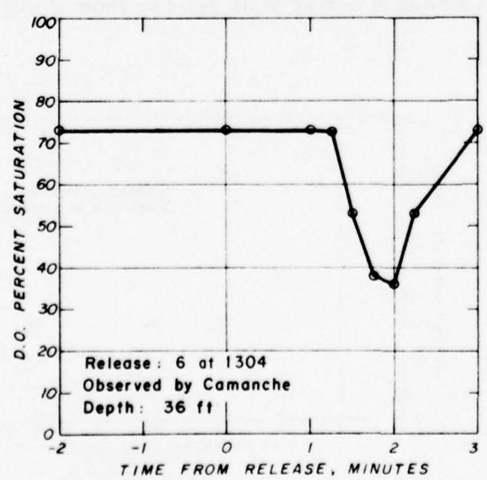


Fig. 11 Oxygen values observed during sixth release by dredge Harding on 29 January 1973.

Interpretation of the Eh values obtained on these two cores is

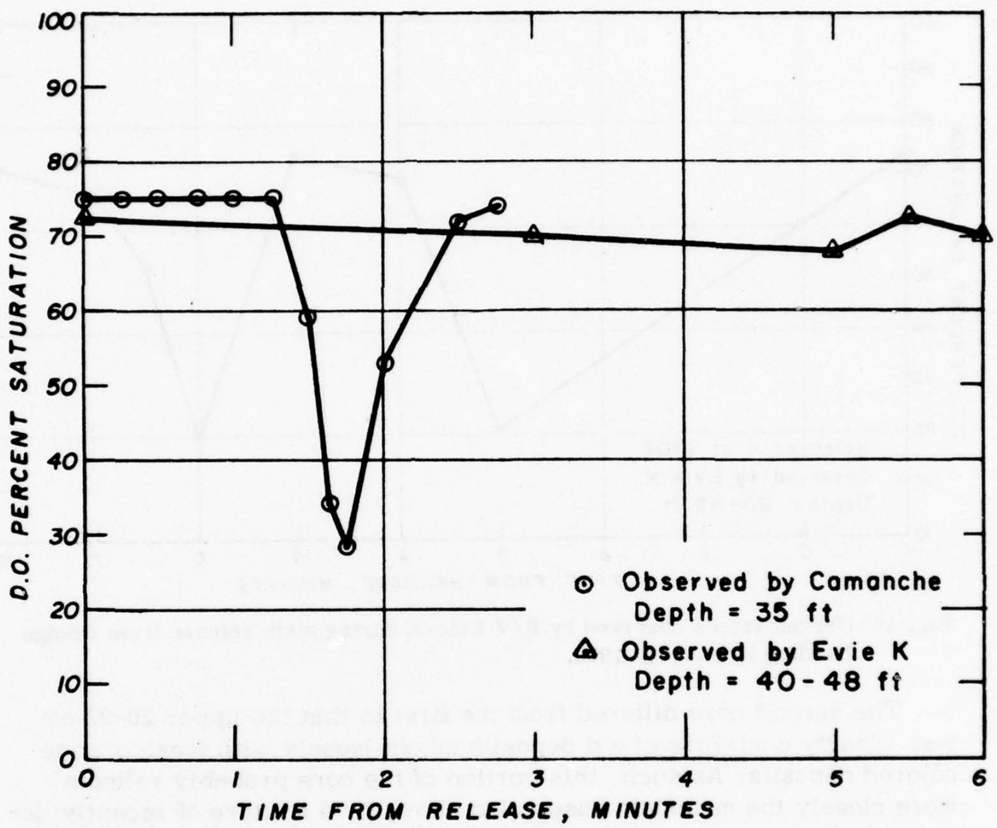


Fig. 12 Oxygen values observed by R/V Camanche during sixth release from dredge Harding 29 January 1973.

difficult. There is probably no area of chemistry in which the relationship between observed values and observed phenomena is more poorly understood. In a matrix as complex as a bottom sediment, an instantaneous Eh (or pH) value represents only the vector of numerous individual reactions which are proceeding simultaneously, few of which are at or near equilibrium. Morris and Stumm (5) remark that "Although aqueous systems containing oxygen or similar oxidizing agents will usually give

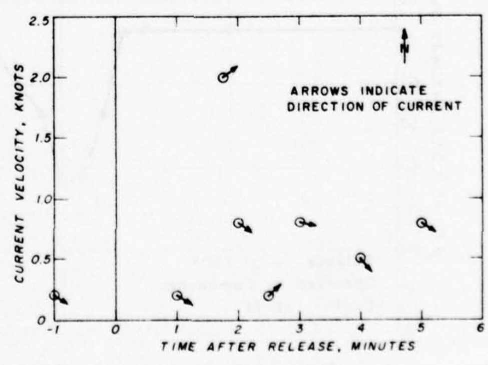


Fig. 13 Turbulence at 43 ft depth after first release by dredge Harding 29 January 1973.

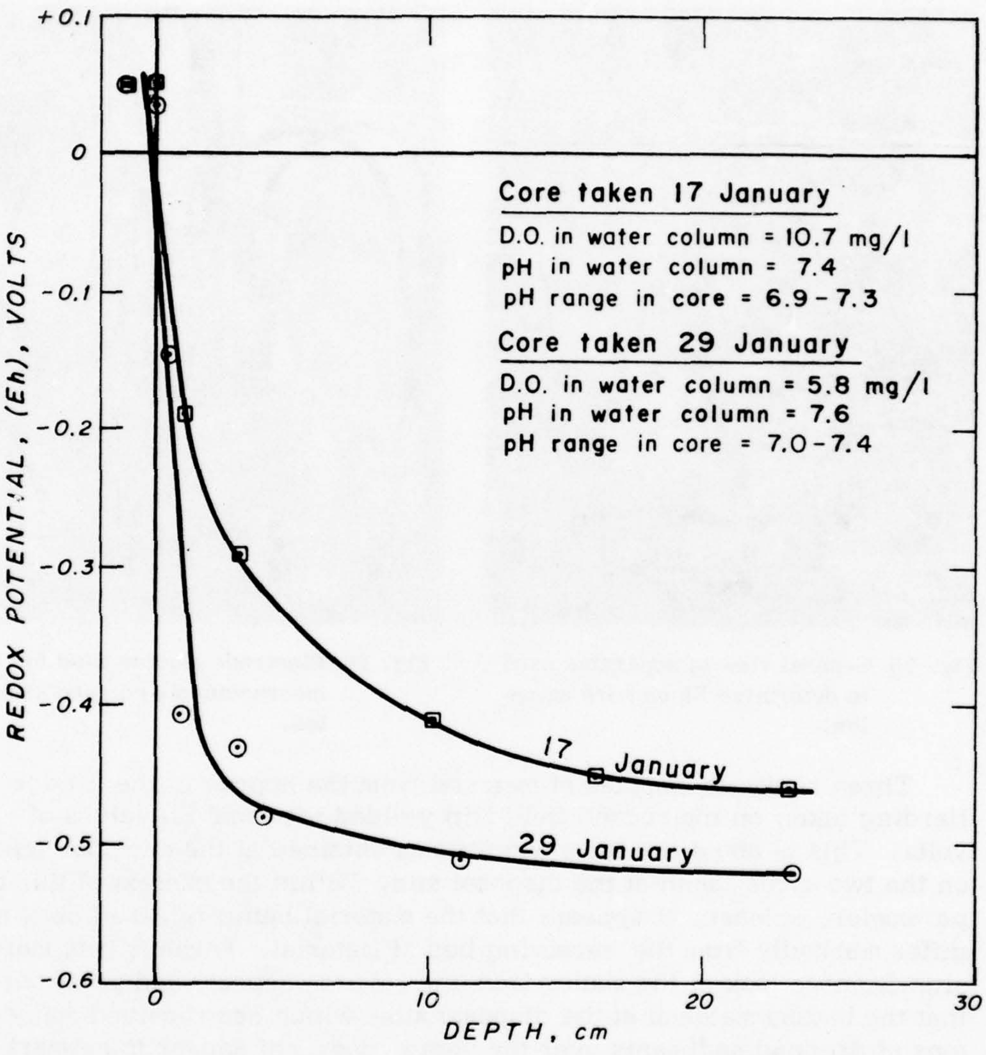


Fig. 14 **Redox potential (Eh) plotted against depth of measurement in sediment cores taken at disposal site.**

positive Eh values and anaerobic systems will usually give negative ones, detailed interpretation is unjustified in most cases". Nevertheless, as the cores were taken with care, it can be assumed that measurements approximate conditions at the bottom. The data show that reducing conditions prevail from the sediment water interface, and that a depth of about 10 cm reducing conditions reach a level where reduction of sulfates can be expected to occur (6).

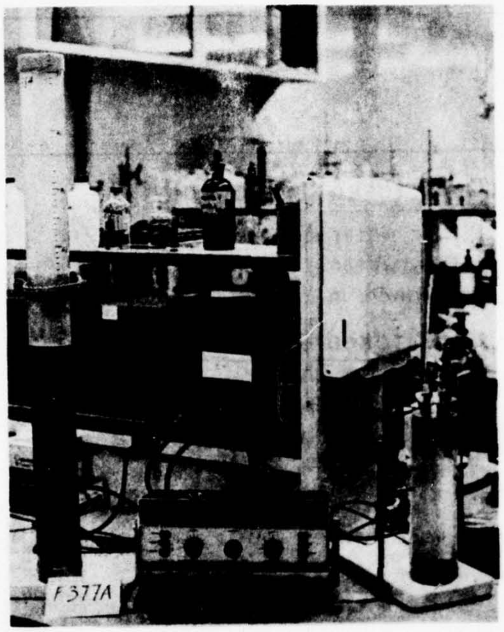


Fig. 15 General view of apparatus used to determine Eh on core samples.

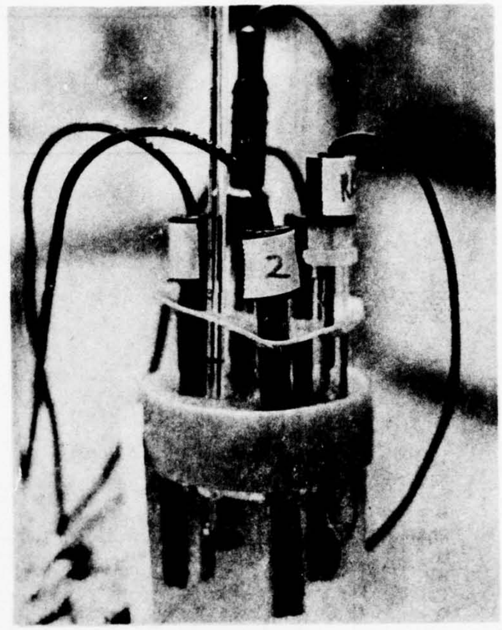


Fig. 16 Electrode cluster used for Eh measurements on core samples.

Three replicate samples of material from the hopper of the dredge Harding taken on the second field trip yielded identical Eh values of -0.47 volts. This is about the same potential as obtained at the one-foot depth on the two cores taken at the disposal site. Within the context of this one parameter, at least, it appears that the material being released does not differ markedly from the receiving bed of material. Perhaps it is more significant to look at the matter from the reverse aspect, and point out that the bottom material at the disposal site, which has received many tons of dredged sediments over the years, does not appear to be markedly different from sediment found at the dredging site. This view agrees well with Krone's (1) discussion of sediment movements within the Bay and its estuaries.

Oxygen uptake was measured on the three samples from the dredge Harding. The data are plotted in Fig. 17. The bulk (greater than 90 percent) of the demand was exerted rapidly, within six minutes. The three samples yielded immediate dissolved oxygen demand values (15 minutes) ranging from 780 to 1240 mg/kg wet weight.

Total sulfides were also determined on the materials from the dredge and also on portions of the bottom cores. The data are summarized in

Table 8. The levels of sulfide found are not unusually high. That sulfides are present is consistent with the Eh values found.

SUMMARY OF FINDINGS AND CONCLUSION

Field monitoring of fourteen releases of freshly dredged sediments at a typical disposal site revealed brief depressions of oxygen content of the receiving water. Depressions lasting not more than 3 to 4 minutes to levels 50 to 70 percent of prevailing dissolved oxygen were reproducibly detected and measured. These were found only near the bay bottom close to the point of release.

We do not believe these effects constitute a significant degradation of water quality that would affect the San Francisco Bay ecosystem. Given moderately polluted dredged material and a disposal site with sufficient

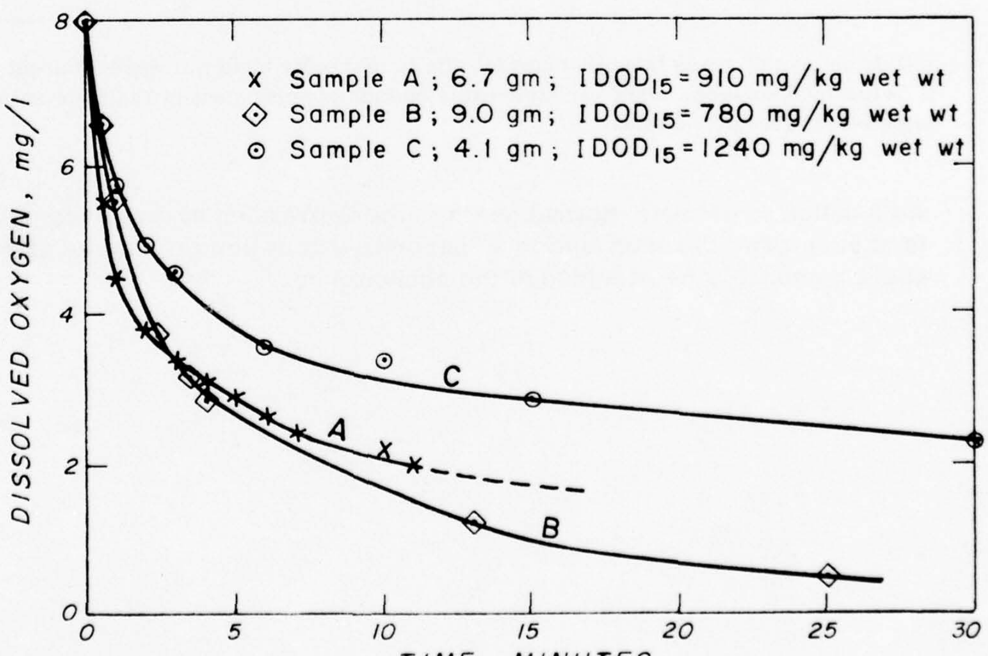


Fig. 17 Oxygen uptake from San Francisco Bay water by portions of sediment taken from dredge Harding 29 January 1973.

Table 8. Sulfide Content of Sediment Samples

Identification	Samples	Sulfides, mg/kg dry wt
17 January 1973 sediment core		
Lab No. 16784-1	Top 1/3rd	66
Lab No. 16784-2	Middle 1/3rd	28
Lab No. 16784-3	Bottom 1/3rd	370
29 January 1973 sediment core		
Lab No. 16979-1	Top 1/3rd	36
Lab No. 16979-2	Middle 1/3rd	1
Lab No. 16979-3	Bottom 1/3rd	250
29 January 1973 from dredge Harding		
Lab No. 16980-1	Portion A	14
Lab No. 16980-2	Portion B	90
Lab No. 16980-3	Portion C	150

Sulfide content of cores taken at disposal site is markedly higher at depth of about one ft below mud surface. This variation explains lack of agreement in replicate sulfide analyses of dredged material.

tidal action to promote normal mixing, the depression of dissolved oxygen is of such brief duration and is so minor in extent that no harmful effects could reasonably be assigned to the phenomenon.

APPENDIX A

1. Ray B. Krone, Testimony before California Regional Water Quality Control Board, San Francisco Bay Region, in behalf of Marine Affairs and Navigation Conference, March 1972.

2. Joel F. Gustafson, "Beneficial Effects of Dredging Turbidity" in World Dredging and Marine Construction, December 1972.

3. Anon, "Effects on Fish Resources of Dredging and Spoil Disposal in San Francisco and San Pablo Bays, California". Special Report, United States Fish and Wildlife Service to United States Corps of Engineers, San Francisco District, 1970.

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5. J. Carrell Morris and Werner Stumm, "Redox Equilibria and Measurements of Potentials in the Aquatic Environment", in Equilibrium Concepts in Natural Water Systems, ACS, 1967.

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APPENDIX B

Field Data and Computed Results

17 January 1973

Table B-1

Vessel: Evie-K Location: Near buoy location Date: 17 January 1973
Dredge: Biddle Background readings Wind: 2k SSE
Current: 0.5 k flood

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0730	7.56	Surface	8.2	8.0	3.6	2.9	70
	7.55	10	8.1	8.0	3.6	2.9	69
	8.0	20	8.1	8.0	5.8	4.8	69
	8.75	30	8.2	8.2	8.4	7.1	70
	7.7	35	7.9	8.5	3.5	2.8	67

Note: Biddle standing by for release. Background readings taken to establish general conditions.

Table B-2

Vessel: Evie-K Location: Near buoy, behind dredge
Date: 17 January 1973 Dredge: Biddle Release No.: 1
Type: Normal Wind: 2k SSE Current: 0.5k flood

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0740	7.76	Surface	9.6	8.2	<1	-	-
	7.76	10	9.3	8.2	<1	-	-
	7.76	20	9.2	8.3	<1	-	-
	7.75	30	9.2	8.2	0.75	.55	78

Note: First release, approaching slack water. No visible plume observed. Evie-K drifted over deep-water channel. Conductivity readings very low.

Table B-3

Vessel: Evie-K Location: In deep water channel off disposal site
Date: 17 January 1973 Dredge: Biddle Background readings
Wind: 2k SSE Current: Slack

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0755	7.64	Surface	9.5	8.2	0.12	0.1	81
	7.62	10	9.5	8.1	0.12	0.1	81
	7.58	15	9.6	8.2	0.23	0.2	82
	7.51	25	9.5	8.2	2.25	2.6	82
	7.60	35	9.6	8.3	3.9	3.1	83
	7.64	40	9.7	8.6	5.6	4.6	84
	7.75	50	9.6	8.8	12.0	10	83
	7.77	55[a]	9.6	8.7	12.5	11	83

[a] Bottom.

Note: Background readings taken in deep water. Reached salt at 50 ft, conductivity meter responding properly.

Table B-4

Vessel: Evie-K Location: Near buoy location Date: 17 January 1973
Dredge: Biddle Background readings Wind: 2k SSE
Current: Slack

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0830	7.67	Surface	10.0	8.0	3.9	3.1	86
	7.62	10	9.8	8.2	4.3	3.4	84
	7.60	15	9.8	8.3	4.6	3.7	84
	7.05	20	9.6	8.4	15.5	14	82
	7.53	30	9.6	8.5	2.4	1.8	82

Note: Background data after return to point 50 ft off Camanche 0830-0900. Standing off while divers work from Camanche.

Table B-5

Vessel: Evie-K Location: Near buoy, behind dredge
Date: 17 January 1973 Dredge: Biddle Release No.: 2
Type: Normal Wind: 6k SE Current: 0.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0902	7.66	Surface	10.2	8.0	7.2	6.0	88
	7.62	10	10.1	8.2	9.8	8.4	86
	7.86	15	10.0	8.2	14.5	13	86
	7.94	20	10.0	8.3	12.0	10	85
	7.54	30	9.7	8.5	1.6	1.2	83
	7.58	43[a]	8.9	8.7	6.3	5.1	77

[a] Bottom.

Note: Biddle passed between Camanche and Evie-K, which moved in behind dredge following release. Plume hard to see, no success with turbidity readings.

Table B-6

Vessel: Evie-K Location: Upstream of buoy Date: 17 January 1973
Dredge: Biddle Background readings Wind: 9k SE
Current: 0.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0920	7.63	Surface	10.3	8.0	9.5	8.2	88
	7.71	10	10.1	8.1	10.2	8.8	86
	8.18	15	10.0	8.2	15.0	13	86
	8.51	20	10.0	8.2	20.4	18	85
	7.57	30	9.8	8.2	2.2	1.7	84
	7.72	40	9.8	9.0	12.5	11	85
	7.74	50	9.8	8.9	15.5	13	85

Note: Biddle dredging. Readings taken at edge of channel. Current rising, cannot take second bottom core. Conductivity changeable, riptides noted.

Table B-7

Vessel: Evie-K Location: Upstream of buoy Date: 17 January 1973
Dredge: Biddle Background readings Wind: 9k SE
Current: 1k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1008	7.64	Surface	10.2	8.1	6.4	5.3	88
	8.18	10	10.1	8.1	17.5	16	86
	8.33	15	10.2	8.2	18.5	17	87
	8.60	20	10.1	8.2	25.5	24	86
	7.60	25	10.1	8.5	20	1.5	86
	7.60	30	10.2	8.2	4.8	3.9	87
	7.79	55	10.2	8.9	13.2	11	88
	7.73	32	10.2	8.4	11.4	9.8	86

Note: Additional background readings while waiting for return of Biddle. Note conductivity variations.

Table B-8

Vessel: Evie-K Location: Upstream of buoy Date: 17 January 1973
Dredge: Biddle Release No. 3 Type: Normal Wind: 6.5k SSE
Current: 1.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1035	8.15	Surface	11.0	8.0	1.3	.95	94
	8.02	10	10.8	8.1	2.6	2.0	92
	7.86	15	10.6	8.2	3.5	2.7	91
	7.80	20	10.5	8.3	3.85	3.1	90
	7.78	30	10.4	8.3	4.4	3.5	88
	7.76	34	10.2	8.5	5.0	4.0	88
	7.86	40	10.2	9.0	11.5	9.7	88
	7.80	44	9.5	9.0	13.7	12	82

Note: Third release profile. Dredge passed between boats. Turbidity on surface hard to see. No success with turbidimeter. Salt water below 30 ft. Rip tides noted. 1155 hr. went aboard Biddle to sample hopper contents. No success.

Table B-9

Vessel: Evie-K Location: 100 ft SE of buoy Date: 17 January 1973
Dredge: Biddle Release No.: 4 Type: Rapid Wind: 5.5k SSE
Current: 1.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1215	8.00	Surface	10.0	8.1	2.4	1.9	85
	7.98	10	9.5	8.2	3.5	2.8	81
	7.93	15	9.5	8.4	4.5	3.6	81
	7.98	20	9.5	8.8	23.4 ?	-	-
	8.05	30	9.5	9.1	16.4	14	83
	8.04	41	9.3	9.2	16.5	14	81
1230	NR[a]	Surface	9.8	8.2	2.4	1.9	84
	NR	10	9.7	8.4	2.5	1.9	83
	8.20	15	9.5	8.6	16.5	22	82
	8.10	20	9.4	8.7	4.7	3.8	82
	8.16	30	9.4	9.1	15.5	13	82
	8.14	39	9.5	9.3	17.5	15	83

[a]Not read.

Note: Two profiles taken. Surface indication that both were in plume of surcharge, but currents probably carried bulk of released material out of range. Release was all at once, less than one minute to empty hopper.

Table B-10

Vessel: Evie-K Location: 100 ft NW of buoy Date: 17 January 1973
Dredge: Biddle Background readings Wind: 9k S
Current: 1.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1240	7.82	Surface	10.3	8.2	1.9	1.5	88
	7.77	10	9.8	8.5	3.1	2.4	84
	7.79	15	9.5	8.6	7.8	6.5	82
	7.86	20	9.4	9.0	12.0	10	81
	7.88	25	9.3	9.0	13.4	11	80
	7.92	30	9.3	9.0	15.0	13	80
	7.85	35	9.3	9.2	16.5	14	81

Note: Profile taken upstream of buoy. Camanche reported oxygen depression on previous release. No indication on Evie-K read-outs.

Table B-11

Vessel: Evie-K Location: 100 ft NW of buoy Date: 17 January 1973
Dredge: Biddle Release No.: 5 Type: Normal Wind: 10k SSW
Current: 2 knots ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1349	8.02	15	9.2	8.0	5.0	4.1	79
	7.97	10	9.2	8.3	5.6	4.6	79
	7.89	5	9.3	8.4	3.8	3.0	80
	7.91	Surface	9.3	8.5	2.8	2.2	80
	7.85	15	9.3	8.7	7.2	5.9	81
	7.90	20	9.4	8.8	9.6	8.1	81
	7.94	30	9.5	8.8	12.0	10	82
1355	7.80	Surface	9.4	8.5	3.1	2.4	80
	7.76	10	9.3	8.5	5.9	4.8	80
	7.79	15	9.3	8.6	6.4	5.2	81
	7.80	20	9.4	8.6	8.1	6.8	81
	7.84	22	9.4	8.8	7.9	6.5	81

Note: Began profile at mid-depth and read up, then down. No depression reported from Camanche. 1400 hrs: wind rising, squalls approaching. Probably blown off course this release.

Table B-12

Vessel: Evie-K Location: 100 ft NW of buoy Date: 17 January 1973
Dredge: Biddle Release No.: 6 Type: Rapid Wind: 10.5k SSE
Current: 3k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1515	7.64	Surface	9.5	8.6	1.85	1.4	82
	7.67	10	9.5	8.8	2.0	1.5	82
	7.61	15	9.5	8.9	2.2	1.7	82
	7.65	20	9.4	8.9	2.4	1.8	81
	7.66	30	8.8	8.8	4.1	3.2	76

Note: Release modified - entire contents of hoppers discharged in less than 1 minute. No effects noted by Evie-K, but Camanche reported distinct depression at bottom.

Table B-13

Vessel: RV Camanche   Location: At buoy location
Date: 17 January 1973   Dredge: Biddle   Background readings
Wind: 9k SE   Current: 0.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0930	7.50	Surface	10.0	8.8	0.2	.15	87
	7.50	5	10.0	8.8	0.2	.15	86
	7.50	10	10.0	8.8	0.3	.22	86
	7.48	15	9 8	9.0	0.5	.36	85
	7.48	20	9.8	9.0	0.6	.43	85
	7.58	38	9.8	9.0	7.5 ?	-	-
	7.56	30	9.8	8.9	3.5 ?	-	-
1005	7.56	25	9.8	9.0	2.5	1.9	85
	7.52	20	9.7	9.0	1.4	1.0	84
	7.47	15	9.7	9.0	0.7	.51	84
	7.46	10	9.6	8.7	0.8	.58	83
	7.44	5	9.6	8.7	0.4	.29	83
	7.40	Surface	9.8	8.7	0.2	.15	85

Table B-14

Vessel: RV Camanche Location: At buoy location
Date: 17 January 1973 Dredge: Biddle Release No.: 3
Type: Normal Wind: 9k SE Current: 1.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1025	7.50	Surface	9.6	8.8	1.0	.73	83
1027	7.51	5	9.5	8.8	1.1	.81	82
1030	7.49	10	9.5	8.9	1.7	1.3	82
1034	7.49	15	9.6	8.9	1.7	1.3	83
1035	7.51	20	9.6	8.9	2.3	1.8	83
1036	7.51	25	9.5	8.9	3.1	2.4	82
1037	7.53	30	9.5	8.9	4.6	3.7	82
1039	7.64	38[a]	9.5	9.1	12.0	10	83
1044	7.60	30	9.4	9.0	7.0	5.7	81
1046	7.59	25	9.5	9.0	4.8	3.8	82
1049	7.56	20	9.5	8.9	3.2	2.5	82
1053	7.56	15	9.4	8.9	1.2	.88	81
1054	7.53	10	9.4	8.9	1.5	1.1	81
1056	7.51	5	9.4	8.9	1.5	1.1	81
1058	7.50	0	9.6	9.0	1.5	1.1	83
1127	7.51	0	9.6	9.0	1.0	.73	83
1129	7.51	5	9.4	9.0	1.2	.88	81
1130	7.51	10	9.3	9.0	1.1	.81	80
1131	7.51	15	9.2	9.0	4.5	3.6	80
1137	7.56	20	9.0	8.0	5.4	4.3	78
1140	7.66	25	9.8	9.0	11.0	9.3	78
1143	7.73	30	9.2	9.2	14	12+	80
1145	7.74	36	9.1	9.2	14	12+	79

[a] Bottom.

Table B-15

Vessel: RV Camanche   Location: At buoy location
Date: 17 January 1973   Dredge: Biddle   Release No.: 4
Type: Rapid   Wind: 5.5k SSE   Current: 1.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1208	7.78	34	9.1	9.3	14.5	12	79
1211	7.78	34	9.2	9.3	14.5	12	80
1213	NR	34	3.0	NR	NR	12	74
1215	7.68	34	8.4	9.5	14.5	13	80
1217	7.80	34	9.2	9.5	15.0	1.3	80
1219	7.71	25	9.0	9.0	8.4	6.9	79
	7.66	20	9.0	9.0	3.6	2.8	78
	7.61	15	9.1	9.0	4.0	3.1	79
	7.63	10	9.2	9.0	1.9	1.4	80
	7.58	5	9.2	9.0	1.6	1.2	80
1226	7.56	0	9.2	9.0	1.5	1.1	80
	7.54	0	9.1	9.0	1.6	1.2	79
	7.53	0	9.2	9.0	1.5	1.1	80
1317	7.50	0	9.3	9.0	1.5	1.1	80
	7.53	15	9.2	9.0	4.8	3.8	80
	7.69	30	8.9	9.2	14.0	12	77
	7.72	35	8.8	9.5	14.0	12	77
1330	7.54	3	9.4	8.9	1.3	.96	81

Table B-16

Vessel: RV Camanche Location: At buoy location
Date: 17 January 1973 Dredge: Biddle Release No.: 5
Type: Normal Wind: 10k SSW Current: 1.5-2.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1339	7.54	15	9.2	9.0	3.8	3.0	80
1342	7.71	35	8.9	9.2	14.0	12	79
1347	7.73	36	8.8	9.4	15	13	72
1351	7.68	25	9.0	9.0	9.5	7.9	74
1354	7.62	15	9.1	9.0	6.6	5.4	79
1355	7.56	3	9.2	9.0	3.5 ?	-	-
1359	7.66	34	8.4	9.4	15	13	81
1414	7.74	35	8.9	9.5	14.5	12	74
1425	7.72	35	8.9	9.3	13	11	77
	7.60	25	9.2	9.0	5.3	4.2	79
	7.61	15	9.4	8.9	4.2	3.3	82
	7.54	3	9.3	9.0	2.3	1.8	80
1449	7.48	2	9.4	9.0	1.1	.81	81
	7.50	10	9.5	9.0	1.9	1.4	82
	7.50	20	9.3	9.0	2.6	2.0	80
1458	7.50	32	9.0	9.0	3.0	2.3	78

Table B-17

Vessel: RV Camanche Location: At buoy location
Date: 17 January 1973 Dredge: Biddle Release No.: 6
Type: Rapid Wind: 10.5k ESE Current: 3k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1512	7.57	34	9.2	9.0	5.6	4.5	79
	7.58	33	8.2	9.0	5.6	4.5	71
1514	7.58	33	6.0	9.0	5.6	4.5	52
	NR	33	5.2	9.0	5.0	4.0	45
	NR	33	7.4	9.0	5.0	4.0	64
	7.56	33	7.0	9.0	4.9	3.8	77
1518	7.56	32	8.9	9.0	4.8	3.8	80
	7.54	20	9.1	9.0	3.5	3.0	78
	7.52	10	9.1	9.0	2.2	1.7	79
	7.49	3	9.2	9.0	1.9	1.4	80
1529	7.46	3	9.1	9.0	1.0	.73	79

Table B-18. Observed Current Velocities and Directions During Field Trip, 17 January 1973

Time, hr	Depth, ft	Direction, degrees from true north	Velocity, knots	Time, hr	Depth, ft	Direction, degrees from true north	Velocity, knots
0930	0	80	1.0	1215	34	280	<0.1
0935	5	90	1.0	1217	34	120	0.6
0940	10	100	1.0	1219	25	120	0.6
0945	15	110	1.0	1221	20	20	0.4
0950	20	130	0.9	1223	15	350	0.3
0955	38[a]	110	0.7	1224	10	280	0.4
0959	30	120	1.5	1225	5	330	0.4
1005	25	120	1.5	1226	0	320	0.4
1010	20	110	1.2	1233	0	290	0.3
1011	15	120	1.0	1250	0	290	0.6
1015	10	110	1.5	1317	0	300	1.5
1020	5	110	1.0	1319	15	290	0.9
1022	0	100	1.0	1320	30	280	0.5
1025	0	80	1.0	1325	35	290	0.3
1027	5	100	1.5	1330	3	290	2.6
1030	10	100	1.5	1339	15	290	1.9
1033[b]				1342	35	290	0.4
1034	15	120	1.5	1346[b]			
1035	20	120	1.0	1347	36	280	<0.1
1036	25	110	1.5	1351	25	290	1.7
1037	30	110	1.5	1354	15	290	1.9
1039	38[a]	120	1.0	1355	3	290	2.0
1044	30	120	1.0	1359	34	280	0.7
1046	25	90	1.0	1414	35	290	1.0
1049	20	100	1.2	1425	35	290	0.2
1053	15	100	1.2	1429	25	300	2.2
1054	10	90	1.2	1430	15	300	2.4
1056	5	90	1.4	1432	3	300	2.6
1058	0	80	1.2	1449	2	32	2.6
1127	0	70	1.2	1453	10	290	2.6
1129	5	80	1.1	1455	20	290	2.2
1130	10	100	0.6	1458	32	290	1.5
1131	15	40 to 120	0.2 to 0.3	1512	34	310	[c]
1137	20	140	0.2	1513[b]			
1140	25	120	0.8	1514	33	290	[c]
1143	30	120	0.7	1518	32	290	[c]
1145	36[a]	120	0.5	1520	20	290	[c]
1208	34	120	0.6	1523	10	300	[c]
1211	34	120	0.5	1525	3	300	[c]
1212[b]							

[a] Bottom. [b] Release. [c] Current meter malfunctioning.

APPENDIX C

Field Data and Computed Results

29 January 1973

Table C-1

Vessel: Evie-K Location: 50 ft from buoy Date: 29 January 1973
Dredge: Harding Background readings Wind: Calm
Current: Slack

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0815	6.88	0	9.8	7.1	7.2	6.2	81
	6.89	2	9.8	7.4	8.0	6.9	81
	6.91	5	9.8	7.9	9.1	7.8	86
	6.86	10	9.9	8.0	10.1	8.7	84
	6.84	15	9.7	8.0	10.5	9.1	82
	6.80	20	9.5	8.0	10.5	9.1	81
	6.91	25	9.4	8.9	16.5	14	81
0822	6.86	26	9.4	9.0	16.0	14	81

Note: Background readings near buoy. Harding had just completed release as we arrived on site.

Table C-2

Vessel: Evie-K Location: 250 yd from buoy, deep water
Date: 29 January 1973 Dredge: Harding Background readings
Wind: Calm Current: Slack

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0831	6.80	25	9.1	8.6	13.8	12	78
	6.74	20	9.1	8.1	11.0	9.5	77
	6.72	15	9.1	8.1	10.5	9.0	77
	6.69	10	9.2	8.0	10.0	8.6	79
	6.66	5	9.2	7.9	8.8	7.5	78
	6.85	35	9.1	9.1	17.0	15	80
	6.91	40	9.0	9.8	23.5	21	80
	6.93	45	9.0	9.8	25.2	22	80
	6.92	60	9.0	9.9	25.5	22	80
	6.92	64	9.9	9.0	25.5	23	86
0840	6.90	50	9.0	9.9	25.5	22	80

Note: Additional background readings taken over deep water channel.

Table C-3

Vessel: Evie-K Location: 100 ft NE of buoy.
Date: 29 January 1973 Dredge: Harding Release No.: 1
Type: Normal Wind: 6-8k NE Current: 0-0.5k (ebb)

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0841[a]	NR	62	6.5	NR	24.0	21	58
	NR	63	3.4	NR	NR	22	30
	NR	55	2.1	NR	20.5	18	19
	NR	60	8.4	NR	25.0	22	74
0843	6.83	55	8.9	10.0	25.5	22	79
	6.82	60	9.0	10.0	25.5	22	80
	6.38	54	2.1[b]	9.9	21.5	19	19[c]
	6.80	60	8.8	10.0	25.5	22	78
	6.81	55	9.0	10.0	25.5	22	80
	8.04	50	9.0	NR	25.5	22	80
	8.04	45	9.0	10.0	25.5	22	80
	8.04	40	9.1	9.9	24.5	22	80
	8.03	35	9.1	9.9	22.5	20	81
	8.03	30	9.3	9.4	20.0	18	81
	7.98	25	9.3	9.0	16.8	15	80
	7.96	20	9.3	8.9	15.5	13	80
	7.88	15	9.3	8.2	10.5	9.0	79
	7.86	10	9.2	8.2	10.0	8.6	79
	7.86	5	9.3	8.1	9.2	7.8	79
0850	7.85	0	8.4	8.1	9.6	8.2	72

[a] Release. [b] Mud. [c] Sensor in mud.

Note: First monitored release by Harding. Evie-K was in channel. Brief depression observed. Submersible pump for turbidimeter not working--open connection in electrical lead. Field repair completed before Run No. 2.

Table C-4

Vessel: Evie-K Location: 200 ft NW of buoy Date: 29 January 1973
Dredge: Harding Release No.: 2 Type: Normal Wind: 6-8k NE
Current: 0.2k (ebb)

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0914	7.84	Surface	9.5	7.8	8.7	7.5	80
	7.84	10	9.9	8.0	9.1	7.8	84
	7.93	20	9.4	8.5	14.0	12	80
	8.01	30	9.4	9.0	17.5	15	82
	8.06	40	9.3	9.6	23.5	21	81
	8.07	50	9.2	10.0	26.0	23	81
	8.07	60	9.2	10.0	26.0	23	81
	8.06	64[a]	4.6[b]	10.0	26.0	23	41[c]
	8.06	63	5.0[b]	10.0	26.0	23	44[c]
0920[d]	8.08	60	9.2	10.0	26.5	23	81
	8.08	60	9.1	10.0	26.5	23	80
		60	8.0	10.0	25.0	22	72
		60	7.4	10.0	24.0	21	66
0925		60	3.7	10.0	24.0	21	32
		59	3.7	10.0	25.5	22	32
		55	7.7	10.0	25.5	22	68
		50	8.8	10.0	25.5	22	78
		55	7.6	10.0	24.0	21	67
		60	4.5[b]	9.8	23.5	21	40
		55	8.5	10.0	26.0	23	75
		50	9.2	10.0	26.5	23	81
		55	8.2	10.0	25.5	22	73

[a] Bottom. [b] Mud. [c] Sensors in mud. [d] Release.

Note: Evie-K still over deep water for this release. Depression observed at 60 ft depth.

Table C-5

Vessel: Evie-K Location: 200 ft NW of buoy Date: 29 January 1973
Dredge: Harding Release No.: 3 Type: Normal Wind: 6-8k NE
Current: 0.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0930	8.08	50	9.1	10.0	26	23	80
	8.08	40	9.2	10.0	24	21	81
	8.05	30	9.4	9.4	18	16	83
	7.92	20	9.4	8.2	12	10	80
	7.89	10	9.4	8.1	9.1	7.8	83
	7.89	Surface	9.4	8.1	8.9	7.6	83
1032		Surface	NR	12.1 ?	8.0	6.1	-
		60	12.4	9.8	26	23	110
		54	5.2[a]	9.9	26.5	24	46[b]
		60	6.2[a]	9.9	24	21	54[b]
		55	8.5	10.0	25.5	22	75
1036[c]		55	5.5	10.0	26	23	48
1037		50	11.2	10.0	26.5	23	99
		60	4.6	9.9	19.5	17	40
1038		55	9.2	10.0	26.5	23	81
		50	10.1	10.0	26.5	23	90
1039		40	10.2	9.6	22.5	20	90
		30	10.2	9.6	22.2	20	89
		20	10.2	8.9	13.2	11	88
		10	10.3	8.2	11.0	9.5	88
		0	10.3	8.1	16.5	15	88
1041		10	10.2	8.1	10.0	8.6	87
		20	10.2	8.6	12.5	11	88

[a]Mud. [b]Sensors in mud. [c]Release.

Note: Third release at 1036. Evie-K still in deeper water of channel. Depression observed.

Table C-6

Vessel: Evie-K   Location: 50 ft SW of buoy   Date: 29 January 1973
Dredge: Harding   Release No.: 4   Type: Normal
Wind: Changing, calm   Current: 0.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1041		30	10.2	9.0	17.5	15	88
		40	10.2	9.9	24.5	22	90
		50	10.2	10.0	26.6	24	91
		58[a]	10.0	10.0	26.6	24	88
1115		0	8.3	8.0	8.10	6.9	71
		10	8.5	8.0	9.4	8.1	73
		20	8.4	8.3	12.5	11	72
		30	8.2	9.2	15.5	13	72
		40	8.0	10.0	25.0	22	71
		50	8.0	10.0	27.0	24	71
1122[b]		0	8.8	8.0	8.0	6.8	75
		50	5.8	10.0	26.0	23	51
		50	8.2	10.0	26.5	23	72
		40	8.3	10.0	26.5	23	73
		50	6.6	10.0	26.6	24	59
		50	5.8	10.0	26.7	24	50
		45	8.0	10.0	26.8	24	71
		48[a]	7.7	10.0	26.9	24	68
		0	8.3	8.8	9.0	7.5	72
		10	8.2	8.1	10.0	8.6	70

[a] Bottom.   [b] Release.

Note: Harding passed between Camanche and Evie-K. Evie-K centered in patch of turbid water behind dredge. No response on turbidimeter.

Table C-7

Vessel: Evie-K Location: Tied to Camanche at buoy.
Date: 29 January 1973 Dredge: Harding Release No.: 5
Type: Normal Wind: 5k E Current: 1k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1130		20	8.3	8.8	13.5	12	72
		30	8.2	9.2	21.5	19	72
		40	8.2	10.0	26.0	23	72
		50	8.2	10.0	27.0	24	72
		52[a]	6.2[b]	10.0	27.0	24	56
1215[c]		0	7.6	7.8	8.0	6.8	64
		30	7.5	9.3	23.5	21	66
1216		40	7.5	9.9	25.5	22	67
		48[a]	5.2[b]	10.0	NR	-	-
1217		40	7.5	10.0	26.1	23	66
		30	7.5	10.0	24.2	21	67
		20	7.4	8.9	13.2	11	63
1300		0	8.4	8.2	7.2	6.0	72
		10	8.5	8.2	9.1	7.7	73
		20	8.4	9.0	16.5	14	73
		30	8.3	9.6	21.5	19	73
		40	8.2	9.9	24.1	21	73
		48[a]	1.2[b]	9.9	22.5	20	11[c]

[a] Bottom. [b] Mud. [c] Sensors in mud.

Note: Both research vessels to port of Harding. Depression found briefly. Decided to tie up to Camanche for future runs and leave monitoring devices overboard throughout release period.

Table C-8

Vessel: Evie-K Location: Tied to Camanche at buoy
Date: 29 January 1973 Dredge: Harding Release No.: 6
Type: Normal Wind: 7k E Current: 2k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1303		40	8.4	9.9	24.0	21	74
1308[a]		43	2.4	10.0	24.0	21	21
		42	7.6	10.0	24.0	21	69
1309		30	8.4	9.5	19.5	17	74
1310		45	2.2	9.9	22.5	20	19
		45	6.0	9.9	22.5	20	53
		45	7.5	10.0	23.5	20	67
1312		40	8.1	9.9	23.7	21	72
		30	8.4	9.2	16.7	14	74
		20	8.7	9.0	15.4	13	75
1314		10	8.8	8.2	8.4	7.1	75
		0	8.9	8.9	4.5	3.6	77

[a]Release.

Note: Rain squalls. Harding passed very close to tethered boats; each observed depression briefly.

Table C-9

Vessel: Evie-K Location: Tied to Camanche at buoy
Date: 29 January 1973 Dredge: Harding Release No.: 7
Type: Normal Wind: 10k SE Current: 2.2k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1358		0	8.2	8.5	7.15	5.9	70
1359		10	8.2	8.2	8.6	7.3	70
		20	8.1	8.9	15.5	13	70
1400		30	8.0	9.0	16.5	14	69
		40	8.1	9.4	20.0	18	71
1401		40	6.6	NR	NR	(18)	58
		43	1.9	NR	NR	(18)	17
1402		38	7.6	9.1	17.9	16	66

Note: Dredge passed about 50 ft to starboard; swung stern to "kick" released material under buoy. Both craft were thus directly in path of released material and both observed oxygen depression.

Table C-10

Vessel: Evie-K Location: Tied to Camanche, at buoy
Date: 29 January 1973 Dredge: Harding Release No.: 8
Type: Normal Wind: 12k SE Current: 3k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1448		0	8.0	8.0	8.0	6.8	68
		20	7.9	8.8	12.6	11	68
1450		30	8.0	9.0	16.1	14	69
		40	7.8	9.0	16.5	14	67
		40	8.1	9.1	16.5	14	71
		45	?	NR	NR	-	-
		40	8.1	NR	NR	-	-
1500		42	8.0	9.0	17.5	15	69
		44	?	9.0	16.0	14	-
		44	2.8[a]	9.0	15.0	13	25[b]
		40	7.8	9.0	16.0	14	67
		42	6.6	9.0	16.0	14	57
		44	2.4[a]	10.0	15.0	13	21
		40	7.8	9.0	16.0	14	67
		30	8.0	9.0	13.5	12	69
1503		40	8.0	9.0	16.0	14	69

[a]Mud. [b]Sensors in mud.

Note: Harding passed to starboard of both boats. Weather coming up, choppy surface.

Table C-11

Vessel: RV Camanche   Location: At buoy   Date: 29 January 1973
Dredge: Harding   Release No.: 1   Type: Normal   Wind: Calm
Current: 0-0.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0817		2	10.0	8.3	7.9	6.6	86
0828		5	10.0	8.5	9.0	7.6	86
		10	10.0	8.8	10	8.4	86
		15	10.0	8.9	10.5	8.9	87
		25	9.6	9.0	14	12	83
		45	9.6	10.3	24	21	82
0838	7.80	45	9.6	10.3	24	21	83
0840	7.56	45	3.6	10.3	24	21	32
	7.74	45	6.2	10.3	24	21	56
0842	7.90	45	8.2	10.3	24	21	73
	7.94	44	9.2	10.3	24	21	82
	7.96	35	9.4	10.0	24	21	84
	7.90	30	9.4	10.0	17	14	85
0849	7.86	25	9.4	9.2	15	13	82
	7.77	20	9.6	9.0	10.5	8.8	83
	7.76	15	9.6	8.8	10	8.4	83
	7.75	10	9.6	8.5	9.3	7.9	82
	7.73	5	9.7	8.3	8.8	7.4	83
0859	7.72	0	9.8	8.2	8.0	6.7	84
	7.74	5	9.4	8.2	8.4	7.1	80
	7.75	15	9.4	8.5	9.4	8.0	81
	7.90	30	9.3	9.5	18.5	16	82
	7.93	44	9.1	10.3	25	22	82

Table C-12

Vessel: RV Camanche Location: At buoy Date: 29 January 1973
Dredge: Harding Release No.: 2 Type: Normal Wind: 6-8k NE
Current: 0.2k (ebb)

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
0923	NR	44	9.0	10.2	25	22	80
0925[a]	7.6	44	4.0	10.2	25	22	36
0926	NR	44	5	10.2	25	22	45
	NR	44	3.6	10.2	25	22	32
	7.58	44	4.2	10.2	25	22	38
	7.64	44	4.8	10.2	25	22	43
	7.68	44	6.2	10.2	25	22	56
	7.60	44	5.0	10.2	25	22	45
	7.66	44	6.2	10.2	25	22	56
	7.80	42	7.0	10.2	25	22	63
0928	7.82	42	7.4	10.2	25	22	66
	7.94	42	8.9	10.2	25	22	80
	7.95	42	9.0	10.2	25	22	80
	7.95	42	8.9	10.2	25	22	80
	7.95	42	9.0	10.2	25	22	80
0932	7.95	42	9.0	10.1	24	21	88
	7.92	30	9.2	9.8	19	16	81
	7.80	20	9.2	9.0	12	10	79
0940	7.77	0	9.6	8.5	0.9	0.6	82

[a]Release.

Table C-13

Vessel: RV Camanche Location: At buoy Date: 29 January 1973
Dredge: Harding Release No.: 3 Type: Normal Wind: 6-8k NE
Current: 0.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1012	7.92	2.5	9.4	8.5	9.6	8.1	80
	7.84	2.5	9.6	8.2	8.2	6.9	82
	7.80	5	9.3	8.5	9.4	8.0	79
	7.89	20	9.2	9.0	15	13	79
	7.97	40	8.8	10.2	25	22	79
1025	7.96	40	8.7	10.1	24	21	77
1035	7.98	40	8.6	10.2	26	23	77
1037[a]	7.88	40	3.2	10.2	26	23	29
	7.96	40	6.0	10.2	26	23	54
1038	7.88	40	8.6	10.2	26	23	77
	7.98	44	8.2	10.1	26	23	72
1043	NR	40	8.6	10.1	26	23	76

[a]Release.

Table C-14

Vessel: RV Camanche   Location: At buoy   Date: 29 January 1973
Dredge: Harding   Release No.: 4   Type: Normal
Wind: Changing, calm   Current: 0.5k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1100		40	8.5	10.2	26	23	76
		20	9.1	9.0	14	12	78
1105		5	9.4	8.5	8.9	7.5	80
		15	9.0	8.6	12	10	77
		30	8.6	9.5	20	18	75
1125		40	8.4	10.1	25	18	74
		40	7.9	10.1	26	23	70
		40	7.8	10.1	26	23	69
1126		40	6.2	10.1	26	23	54
		40	6.8	10.1	26	23	60
		40	6.2	10.1	26	23	55
1127		40	7.8	10.1	26	23	69
		40	6.4	10.1	26	23	56
		40	7.9	10.1	26	23	70
		40	8.0	10.1	26	23	71
1128		40	7.9	10.1	26	23	70
		40	7.6	10.1	26	23	67
1129		40	8.1	10.1	26	23	72
		40	8.2	10.1	26	23	72
1130		40	8.1	10.1	26	23	73

Table C-15

Vessel: RV Camanche   Location: At buoy   Date: 29 January 1973
Dredge: Harding   Release No.: 5   Type: Normal   Wind: 5k E
Current: 1k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1134		30	8.4	10	23	20	74
		20	9.2	9	14	12	79
1151		20	9.1	9	14	12	78
		4	9.3	8.3	8.6	7.3	79
1205		10	9.1	8.7	9.6	7.2	79
		15	8.9	8.9	10.5	8.1	78
		20	8.6	9.0	15	8.9	77
		25	8.4	10.0	21	13	74
		30	8.4	10.0	25	18	74
		35	8.4	10.5	26	22	74
1214		39	8.4	10.5	26	23	74
1218[a]		38	8.4	10.5	26	23	75
		38	8.2	10.5	26	23	73
1219		38	6.4	10.5	26	23	58
		38	8.0	10.5	26	23	72
		38	7.4	10.5	26	23	66
1220		38	8.0	10.5	26	23	72
		38	8.3	10.5	26	23	74
1221		38	8.3	10 5	26	23	80

[a] Release.

Table C-16

Vessel: RV Camanche Location: At buoy Date: 29 January 1973
Dredge: Harding Background readings Wind: 7k E
Current: 1-2k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1227	7.97	38	8.2	10	26	23	72
	7.95	30	8.3	10	23	20	73
	7.95	25	8.3	10	24	21	73
	7.94	20	8.4	10	21	18	74
	7.83	15	8.8	9	12	10	76
	7.78	10	9.0	8.9	11	9.3	77
	7.78	5	9.1	8.6	9.5	8.0	78
1238	7.70	0	9.2	8.4	8.6	7.2	79
1300	7.84	2	9.2	8.5	8.6	7.2	79
	7.78	10	9.2	8.5	9.3	7.9	79
	7.88	20	8.6	9.1	18	16	75
	7.95	30	8.4	10	24	21	74
	7.94	35	8.3	10	24	21	73
1308	7.96	36	8.2	10	25	22	73

Table C-17

Vessel: RV Camanche Location: At buoy Date: 29 January 1973
Dredge: Harding Release No.: 6 Type: Normal Wind: 7k E
Current: 2k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1308[a]	7.96	35	8.2	10	25	22	73
1309	NR	35	8.2	10	25	22	73
	NR	35	6.0	10	25	22	53
	7.66	35	4.2	10	25	22	38
	NR	35	4.0	10	25	22	36
1310	7.88	35	6.0	10	25	22	53
	7.94	35	8.2	10	25	22	73
	7.95	35	8.3	10	25	22	73
1313	7.95	30	8.4	10	23	20	74
	7.88	21	8.7	9.0	14	12	75
	7.83	10	9.0	9.0	13	11	77
	7.75	5	9.2	8.5	8.4	7.2	79
1343	7.72	5	9.2	8.7	8.8	7.4	79
	7.79	10	9.1	9.0	12	10	78
	7.80	15	9.0	9.0	13.5	12	77
	7.84	20	8.9	9.0	15	13	77
	7.85	25	8.6	9.0	16	14	74
	7.86	30	8.6	9.2	16.5	14	75
1352	7.89	35	8.5	9.3	17.5	15	75

[a]Release.

Table C-18

Vessel: RV Camanche Location: At buoy Date: 29 January 1973
Dredge: Harding Release No.: 7 Type: Normal Wind: 10k SE
Current: 2.2k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1358[a]	7.91	35	8.4	9.6	19	17	74
	NR	35	8.3	9.6	19	17	73
	NR	35	8.3	9.6	19	17	73
	NR	35	8.3	9.6	19	17	73
1359	N	35	8.3	9.6	19	17	73
	7.65	35	6.0	9.6	19	17	52
	NR	35	4.4	9.6	19	17	38
	NR	35	7.6	9.6	19	17	66
	NR	35	8.2	9.6	19	17	72
1400	NR	35	7.6	9.6	19	17	66
	NR	35	7.1	9.6	19	17	62
	NR	35	8.1	9.6	19	17	71
	NR	35	8.2	9.6	19	17	72
	7.84	35	8.2	9.6	19	17	72
1402	7.83	35	8.2	9.6	19	17	72
	7.84	28	8.5	9.2	16	14	75
1406	7.84	35	8.4	9.4	17	15	74
	7.78	20	8.8	9.0	11.5	9.7	76
1421	7.72	4	9.4	8.2	7	58	80

[a]Release.

Table C-19

Vessel: RV Camanche Location: At buoy Date: 29 January 1973
Dredge: Harding Release No.: 8 Type: Normal Wind: 12k SE
Current: 3k ebb

Field readings						Computed values	
Time, hr	pH	Depth, ft	D.O. reading, mg/l	Temp., C	Cond. reading, mmhos/cm	Salinity, ppt	D.O. percent sat.
1443	7.69	4	9.4	8.5	7.8	6.5	80
	7.74	15	9.2	9.0	11	9.3	79
1446	7.85	30	8.8	9.2	17	15	77
	7.85	33	8.7	9.2	17	15	76
1453	7.87	34	8.6	9.2	17	15	75
1459[a]	7.86	34	8.6	9.2	17	15	76
	NR	34	8.5	9.2	17	15	75
1500	7.68	34	8.6	9.2	17	15	76
	NR	34	8.6	9.2	17	15	76
	NR	34	6.8	9.2	17	15	59
	NR	34	4.0	9.2	17	15	34
			3.2				28
1501	NR	34	6.0	9.2	17	15	53
	NR	34	8.2	9.2	17	15	72
	7.84	34	8.4	9.2	17	15	74
1502	7.84	34	8.6	9.0	15	13	76
1504	7.83	34	8.6	9.2	15.5	13	76

[a] Release.

Table C-20. Observed Current Velocities and Directions During Field Trip, 29 January 1973

Time, hr	Depth, ft	Direction, degrees from true north	Velocity, knots	Time, hr	Depth, ft	Direction, degrees from true north	Velocity, knots
0817	2	100 to 160	0.1	1037	40	110	0.9
0828	5	120	0.5	1037:30	40	120	0.3
0833	15	120	0.5	1038	40	80	0.4
0836	25	120	1.2	1039	40	120	<0.1
0837	43[a]	120	0.2	1040	40	80	0.4
0838[b]				1041	40	100	0.3
0839	43	120	0.2	1042	40	120	0.2
0839:45	43	50	2.0	1043	40	120	0.2
0840	43	120	0.8	1100	40	140	0.2
0840:30	43	60	0.2	1101	20	160	0.1
0841	43	100	0.8	1102	20	280	0.1
0842	43	140	0.5	1103	20	280	0.2
0843	43	120	0.8	1104	20	300	0.2
0846	35	120	1.1	1105	5	300	0.2
0847	30	120	1.0	1109	15	300	1.0
0849	25	120	1.2	1112	30	300	0.5
0851	20	120	0.4	1114	40	300	0.1
0853	15	120	0.2	1121	40	340	0.2
0856	10	120	0.3	1125[b]			
0857	5	120	0.2	1126	40	300	0.2
0859	1	300	<0.1	1127	40	300	0.2
0909	5	32	<0.1	1128	40	300	0.3
0911	15	120	0.2	1130	40	320	0.4
0917	30	100	1.2	1133	40	340	0.5
0922	44	120	0.8	1134	30	300	0.4
0923	44	150	0.6	1135	20	300	1.0
0924[b]				1140	20	300	1.0
0925:30	44	60	1.5	1151	20	300	1.0
0925	44	120	0.5	1156	4	290	1.8
0925:15	44	140	0.8	1200	4	290	1.8
0925:30	44	100	0.2	1209	25	300	1.0
0930	44	140	0.6	1210	30	310	0.5
0931	44	120	0.8	1211	35	330	0.4
0932	42	120	0.7	1214	39	320	0.4
0933	30	120	1.1	1218[b]			
0934	30	120	1.0	1218:30	38	20	0.8
0935	20	120	0.5	1219	38	300	0.3
1027	40	120	0.2	1220	38	300	0.5
1035	40	120	0.2	1221	38	300	0.6
1036[b]				1227	38	290	0.6

Table C-20. Observed Current Velocities and Directions During Field Trip, 29 January 1973 (cont'd)

Time, hr	Depth, ft	Direction, degrees from true north	Velocity, knots	Time, hr	Depth, ft	Direction, degrees from true north	Velocity, knots
1231	25	300	1.3	1346	15	300	2.6
1233	20	310	1.4	1349	25	300	1.9
1234	15	300	1.6	1352	35	300	1.4
1236	10	300	2.0	1358[b]			
1238	1	300	2.2	1359	35	300	2.0
1244	10	300	2.2	1400	35	300	0.8
1302	10	300	2.5	1401	35	300	1.5
1306	35	300	1.1	1405	28	300	1.8
1308[b]				1406	35	300	1.5
1309	35	300	1.5	1416	20	300	2.1
1310	35	300	1.5	1421	4	300	2.8
1311	35	300	1.0	1443	4	300	2.8
1313	30	290	1.2	1444	15	300	2.5
1323	21	300	2.3	1446	30	300	1.9
1327	5	300	2.6	1448	33	300	1.9
1343	5	320	2.6	1453	34	300	1.5

[a] Bottom.

[b] Release.

APPENDIX D

INSTRUMENTATION

Martek Mark II

The Martek units used for this study utilize a probe-cluster suspended from the electrical cable connecting the sensors to a read-out unit on deck of the research vessel. The individual probes are described below:

Depth: This is a diffused silicon diaphragm-type transducer, calibrated electronically and compared to an internal reference. Read-out was adjusted to read in feet, and specified accuracy is ± 1 percent of fullscale (±3 ft).

Temperature: The temperature probe is a thermister, electronically compensated for linearity. Specified accuracy is ±0.2 C.

Conductivity: The conductivity cell is a pair of platinized nickel electrodes forming one leg of a wheatstone bridge circuit in which a known resistance forms the internal reference. Accuracy is ±2 percent fullscale, ±1 millimho.

pH: The pH probe is a glass combination electrode. A reference electrode is immersed in pH 7.0 buffer within the probe itself, providing automatic temperature correction. The amplified differential voltage from the two electrodes is displayed. The system is accurate to ±0.1 pH units, though electronic resolution allows reading to ± 0.01 pH unit.

Dissolved Oxygen: This is a polarographic cell utilizing the gold/silver couple and a teflon diffusion membrane. Readings are temperature compensated electronically within the read-out unit utilizing a separate thermister located adjacent to the membrane; the probe is provided with a motor-driven stirrer to assure ample fluid flow past the membrane. Specified accuracy is ±1 percent fullscale, normally ±0.1 part per million. Calibration may be achieved in several ways, but for the purposes of this study, the calibration point was 100 percent saturated zero-salinity water. Data reduction (see Appendix F) included correction of field readings for the varying salinities encountered.

Bendix Q-15 Ducted Current Meter (Recording): Current measurements were recorded with a Bendix Q-15 ducted current meter which senses both speed and direction and records on a custom

built, chart paper system. Speed is compensated for oscillatory wave motions, so that only the net current is recorded. The current meter is oriented in the direction of the net current flow by a 10-ft vane. Direction is referenced to magnetic north by a compass contained within the current meter housing. The meter is electrically connected to the recording unit, where the sensor outputs are electronically processed and recorded on a multiplexing dual-channel recorder. The ducted current meter system hs an accuracy of ±0.03 knots in the speed range from 0 to 1 knot, ±0.3 knots in the range 0-10 knots, and ±5 degrees in the direction range 0 to 360 degrees.

<u>Falling Stream Turbidimeter (Hach)</u>: This turbidimeter measured the absorption of light, in units of optical density, from a beam passing through a smooth stream of the liquid to be measured. There is no "cell" and no consequent fouling. The active element in the measuring circuit is a selenium-type photocell, which in the configuration used failed to respond adequately to small changes in turbidity. Samples taken in the field were to have been used to standardize the instrument in terms of Jackson Turbidity Units, but instead these samples were simply used to document the existing turbidity levels at the field sites. The unit is essentially insensitive to variations in color.

APPENDIX E

LABORATORY PROCEDURES

References: "Standard Methods for the Examination of Water and Wastewater", APHA, AWWA, and WPCF, 13th edition, 1971.

"Annual Book of ASTM Standards", American Society of Testing and Materials, 1972.

Parameter	Procedure
Sulfides	Standard Methods, p. 552
Volatile solids	Standard Methods, p. 538
Total solids	Standard Methods, p. 535
Eh	ASTM, D1498
pH	Glass electrode, Ag-AgCl references
COD	Standard Methods, p. 495
Grain size distribution	ASTM, D422-63(72)
Immediate dissolved oxygen demand	Initial D.O. of a BOD-bottle of oxygenated San Francisco Bay water was taken by a Weston/Stack DO probe (polarographic), with a stirring bar in motion in the bottle. The stirring was then stopped and a wet sample introduced with a spatula. The probe was inserted again and stirrer started. This was time 0, and readings were taken at intervals up to 30 minutes.
Turbidity	Hach Laboratory Turbidimeter Model 2100
Conductance	Industrial Instruments Co. Conductivity Bridge Type RC

APPENDIX F

DATA REDUCTION

Eh: Millivolt readings were taken against the saturated calomel reference electrode with a Corning Model 110 expanded digital millivolt meter on three platinum electrodes. Where the three electrodes agreed to ± 10 mv, the three readings were averaged. Where only two electrodes agreed to ± 20 mv, the third reading was dropped and the two readings averaged. Eh was then calculated using the result obtained above in the formula:

$$\text{Eh, volts} = \frac{\text{mv} - C}{1{,}000}$$

Where $C = 244.0$ mv $\pm 0.25 \Delta_t$ (Standard potential of saturated calomel electrode referred to hydrogen electrode).

DO: Field martek DO readings were first corrected for effects of salinity. This was accomplished by the formula:

$$\frac{O_2 \text{ solubility (ppm) at observed temperature and salinity}}{O_2 \text{ solubility (ppm) at 0 salinity and same temperature}} \times \text{Field reading}$$

In order to do this, salinity had to be determined first. This was accomplished on a Wang 600 - 2 - TP Programmable Calculator, using the formulas of Chesapeake Bay Institute, Johns Hopkins University (9) to derive chlorinity, followed by the computation:

$$\text{Sal} = 0.030 + (1.8050 \times \text{Cl})$$

From the observed temperature and chlorinity, the level of DO that would be 100 percent saturation was then derived for selected data points by means of computer-generated tables published by Department of Oceanography, Oregon State University (10), based on the computations of Carpenter. Finally, percent saturation was derived from the corrected Martek readings according to the formula:

$$\text{Percent saturation} = \frac{\text{100 percent saturation for conditions given, ppm}}{\text{corrected readings, ppm}} \times 100$$

APPENDIX G

Diver Debriefing Forms

BROWN AND CALDWELL

DIVER DEBRIEFING

DATE 1-17-73 STATION stationary - buoy site

DIVERS IN T. Glimme

OUT

WEATHER partial overcast WIND 0-5 k

SEA STATE calm TIDAL CONDITIONS slack

DIVING FUNCTIONS to obtain bottom sediment core

VISIBILITY AND TURBIDITY (sight distance, material in suspension, etc.)

vis = 0 Turbidity high very heavy silt

TURBULENCE (currents, surge, catenary and scope of line, etc.)

calm with increasing upriver current at bottom

BOTTOM CONDITIONS: TYPE OF SEDIMENT (clay, silt, sand, etc.)

COMPACTION OF SEDIMENT (penetration, etc.) slight penetration

TOPOGRAPHY (smooth, ripple marks, scour, etc.)

felt lots of debris

MARINE LIFE: BENTHIC

heavy crop small crustaceans observed in column above core when surfaced

PELAGIC

none observed

ORGANIC MATERIAL not observed

SAMPLES OBTAINED 1 core 18" x 3" with water covering

RESULTS OF FUNCTIONS

Recorded by: T. Glimme

G-2

BROWN AND CALDWELL

DIVER DEBRIEFING

DATE 1-29-73 STATION tied to buoy

DIVERS IN G. Gamble
OUT

WEATHER overcast WIND calm

SEA STATE calm TIDAL CONDITIONS slack

DIVING FUNCTIONS to obtain bottom core

VISIBILITY AND TURBIDITY (sight distance, material in suspension, etc.)

poor vis, < 0.1 "

TURBULENCE (currents, surge, catenary and scope of line, etc.)

calm

BOTTOM CONDITIONS: TYPE OF SEDIMENT (clay, silt, sand, etc.)

COMPACTION OF SEDIMENT (penetration, etc.) ~2'

TOPOGRAPHY (smooth, ripple marks, scour, etc.)

no rubble

MARINE LIFE: BENTHIC crustaceans observed in column above sediment when surfaced

PELAGIC

none observed

ORGANIC MATERIAL not observed

SAMPLES OBTAINED

1 core 18" x 3" (sed) with water covering

RESULTS OF FUNCTIONS

Recorded by: G. Gamble

INCLOSURE 9

Dredge Spoils Disposal Monitoring
San Pablo Bay - February 5, 1974
Contract No. DACW07-74-C-0044

U. S. ARMY CORPS OF ENGINEERS
SAN FRANCISCO DISTRICT

DREDGE SPOILS DISPOSAL MONITORING

SAN PABLO BAY – FEBRUARY 5, 1974

MARCH 1974

ENVIRONMENTAL QUALITY ANALYSTS, INC.

ENVIRONMENTAL
QUALITY
ANALYSTS
INC.

A DIVISION OF BROWN AND CALDWELL
SAN FRANCISCO ALHAMBRA

J. T. NORGAARD, P.E. 6821C President
T. V. LUTGE, P.E. 9219C Vice-President
M. L. WHITT, P.E. 15118C General Manager
M. N. LIPSCHUETZ Technical Director
R. D. SMITH Senior Oceanographer
J. B. TYLER Laboratories
C. P. WALTON, Ph.D. Water Chemist

April 17, 1974

L203A

Colonel J. L. Lammie
District Engineer
San Francisco District
U.S. Army Corps of Engineers
100 McAllister Street
San Francisco, California 94102

Subject: Dredge Spoil Disposal Monitoring Study

Gentlemen:

In accordance with the agreement, contract number DACW07-74-C-0044 dated January 22, 1974, we submit herewith the final report on a monitoring study of dredge spoil disposal operations conducted in San Pablo Bay in February 1974.

We will be pleased to meet with you or your staff to discuss our report at your convenience.

Very truly yours,

ENVIRONMENTAL QUALITY ANALYSTS, INC.

Robert D. Smith
Senior Oceonographer.

INTRODUCTION

This report presents the results of an investigation conducted for the U.S. Army Corps of Engineers, San Francisco District, to monitor the effect of dredge spoil disposal on receiving water quality. The field survey was carried out on February 5, 1974, at the dredge spoil disposal site in San Pablo Bay. The survey vessel employed was the Government vessel Grizzly. Monitoring consisted of measuring dissolved oxygen, light transmittance, conductivity, pH, temperature, and current speed and direction at selected fixed depths in the receiving water in the vicinity of the dredge during release of the dredge spoil. Similar measurements were obtained concurrently by U.S. Army Corps of Engineers personnel also aboard the Grizzly.

Objective

The objective of the monitoring study was to observe whether the disposal of dredge spoil resulted in a reduction of dissolved oxygen in the receiving water and, if observed, to determine the duration of time before dissolved oxygen returned to background values.

Scope of Work

The scope of work was initially set forth in specifications issued on January 18, 1974, by the U.S. Army Corps of Engineers. The field survey was to include activities as follows:

1. From the vessel Grizzly, monitor dredge spoil releases from the dredge at two stations. One station was to be 100 to 125 meters from the dredge, while the other was to be as close as safety permitted. Responsibility for locating the stations was to be given to the master of the dredge.

2. Parameters, which include dissolved oxygen, turbidity, and current velocity, were monitored initially at one-minute intervals for five minutes, followed by measurements at five-minutes intervals until release of the dredge spoil (signaled from the dredge by a horn blowing). Beginning with the horn signal, measurements were to be recorded at fifteen-second intervals for five minutes, then at one-minute intervals for another five minutes. If, at this point, any observed oxygen sag had disappeared and dissolved oxygen had returned to background levels, then measurements were to be recorded at five-minute intervals until thirty-five minutes after the release. Otherwise recordings were to continue at one-minute intervals for another five-minutes. This procedure was to be followed at each of the two stations in the bottom, center, and top of the lower water mass for a total of six samplings.

SURVEY EQUIPMENT

Measurements of dissolved oxygen, turbidity, specific conductivity, temperature, depth and pH were obtained using a water quality analyzer and transmissometer. The sensors, listed in Table 1, are mounted together as a single unit that is lowered by means of the electrical cable that connects to the deck readout unit. The data are digitally recorded using a data digitizer and recorder that simultaneously digitizes all six parameters and displays, prints and produces a computer-compatible tape either upon command or automatically at regular intervals up to 2.7 times per second, governed by a digital clock.

Table 1. Parameters Measured During Dredge Spoil Disposal Monitoring

Parameter	Method of *Measurement*	*Accuracy*	Indicating and *Recording Methods*
Dissolved Oxygen[a]	Auto-Temperature Compensated Polarographic Gold/Silver Electrode	± 1% Full Scale, ± 0.2 Parts Per Million	Digital, Printed Paper Tape ASCII Coded Mylar Tape
Turbidity, Light[c] Transmittance	25-cm Path XMS Transmissometer	± 1% Full Scale	Digital, Printed Paper Tape ASCII Coded Mylar Tape
	10-cm Path Hydro Products Model 612 Transmissometer	± 2% Full Scale	
Specific Electrical Conductivity	Five-Electrode Guarded Kelvin Cell	± 0.02 millimho/cm	Digital, Printed Paper Tape ASCII Coded Mylar Tape
Temperature[b]	Transistor Probe	± 0.1 C ± 0.01 C Resolution	Digital, Printed Paper Tape ASCII Coded Mylar Tape
Depth	Pressure Transducer	± 1% Full Scale, ± 1 Foot	Digital, Printed Paper Tape ASCII Coded Mylar Tape
pH	Glass and Silver/ Silver Chloride Electrodes	± 0.1 pH Unit ± 0.01 Unit Resolution	Digital, Printed Paper Tape ASCII Coded Mylar Tape
Current Speed and Direction	Ducted Current Meter	± 0.03 kt. and ± 5 Deg.	Analog Chart Paper Recorder

a Calibrated during survey using Winkler titration procedure.
b Temperature measuring systems are checked for accuracy with N.B.S. calibrated thermometers.
c The 25-cm transmissometer was used on the first run; the 10-cm unit was used on all other runs.

Current measurements were obtained with a ducted current meter, described in Table 1, which senses both speed and direction and records on an analog recorder. Speed is compensated for oscillatory wave motion, so that only the net current speed is recorded. The current meter is oriented in the direction of the net current flow with a 10-foot long vane. Direction is referenced to magnetic north by a compass contained within the current meter housing. The meter is lowered by means of a wire cable wound on a winch. A separate electrical cable is used to connect the meter to the deck recording readout.

SURVEY PROCEDURES

The field survey consisted of monitoring six separate releases of dredge spoil from the hopper dredge Chester Harding. This dredge has a 2,700 cubic-yard capacity and is operated by the U.S. Army Corps of Engineers. Monitoring was conducted from the survey vessel Grizzly, which was anchored in the disposal area, shown on Fig. 1, for the duration of the survey. The period of monitoring is shown on the predicted tide curve for Golden Gate also on Fig. 1. Charted water depth at the survey site is approximately 11 meters (36 feet).

The dredge spoil was released up current of the Grizzly at a distance of 30 to 60 meters for the first three releases and at a distance of 100 to 125 meters for the second three releases. Prior to each release, the sensors of the water quality analyzer and the current meter were lowered to one of three selected monitoring levels. The levels were chosen to be near the bottom, center and top of the lower water mass. The lower water mass is considered to contain water with salinity near seawater value and which is separated from the brackish upper water mass by a steep vertical gradient of salinity. Vertical profiles obtained using the water quality analyzer prior to some of the releases aided determination of the proper monitoring level. In no case, however, was any level closer than 15 feet to the water surface, since this is the approximate depth at which the dredge releases the spoil.

Making use of the sampling capacity of the water quality analyzer, receiving water parameters were simultaneously recorded at five-second intervals for at least ten minutes following the horn signal, at which time, the sampling interval was increased to five minutes. At various times during the sampling, water samples were collected at the monitoring level for determination of dissolved oxygen concentration by means of Winkler titration for the purpose of checking the calibration of the electronic dissolved oxygen sensor.

Current speed and direction were recorded continuously throughout each sampling period.

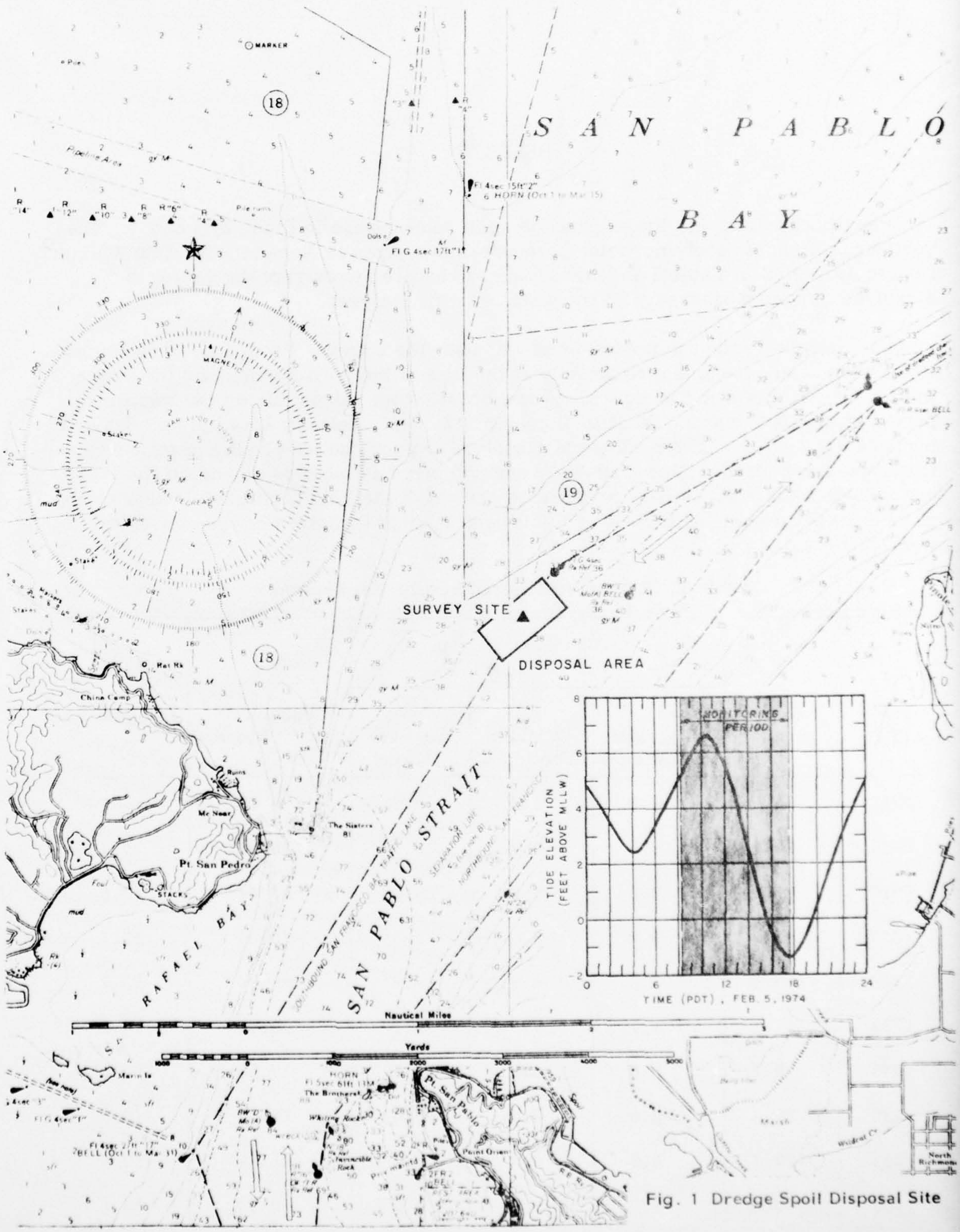


Fig. 1 Dredge Spoil Disposal Site

RESULTS

Results of monitoring the six dredge spoil releases are in Figs. 2, 3 and 4. The vertical profiles of receiving water parameters are given in Appendix A. The Winkler results are listed in Table 2 and were used as required to correct the values of dissolved oxygen measured with the water quality analyzer.

For Release 1, the monitoring level was near the bottom. Recording of receiving water parameters began approximately at the time of the horn signal, and the data are in Fig. 2. As shown in the figure, typical background values during the sampling period of Release 1 were: dissolved oxygen 8.2. mg/l, salinity 21.4 ppt, pH 8.1 and temperature 10.7 C. Lower values of dissolved oxygen, salinity, pH and temperature that appeared beginning approximately one and one-half minutes and again five minutes after the horn signal accompanied arrival of the field of diluted dredge spoil at the survey vessel. At this time, the lowest value of dissolved oxygen observed was 7.7 mg/l.

Table 2. Dissolved Oxygen Sensor Calibration

Time PDT	Depth m	Dissolved Oxygen ppm			Conductivity millimhos/cm	Temperature C
		Winkler Titration-1	Winkler Titration-2	Water Quality Analyzer		
0817	11.6	8.8	8.9	8.5	24.00	10.7
0950	10.1	8.5	8.7	8.4	25.04	10.7
1010	7.6	8.8	8.8	8.2	23.44	10.6
1050	7.9	8.7	8.6	7.9	25.64	10.7
1148	6.4	8.5	8.5	7.8	26.14	10.7
1330	10.1	8.7	8.6	9.1	26.12	10.7
1345	9.7	8.8	8.8	8.5	25.60	10.6
1420	10.4	8.6	8.5	8.6	25.70	10.7
1515	10.7	8.9	8.9	8.8	21.58	10.5
1700	7.0	9.8	9.9	9.8	10.10	10.0

A 25 cm light path transmissometer was used for turbidity measurements on Release 1, but background turbidity conditions were too high for effects of dredge spoil to be seen. Therefore, before Release 2 began, this instrument was replaced with a 10-cm transmissometer. Current measurements were not obtained during the first release due to insufficient time before the release to prepare the current meter for lowering.

The monitoring level during Release 2 was in the center of the lower water mass, and the recorded receiving water parameters are in Fig. 2. Typical background values were: dissolved oxygen 8.6 mg/l, light transmittance 1 percent, salinity 22.0 ppt, pH 8.1 and temperature 10.7 C. Arrival of the dredge spoil field at the survey vessel occurred at approximately one minute and again at three minutes after the horn signal. As during Release 1, salinity was lower in the field, but in contrast to Release 1, dissolved oxygen was slightly higher. Light transmittance was decreased to less than 0.1 percent in the field, and temperature was decreased to 10.5 C. Throughout Release 2, current speed was approximately 1 knot toward the northeast. Neither the release nor passage of the dredge spoil field past the survey vessel appeared to affect the current.

The monitoring level during Release 3 was near the top of the lower water mass, and the data are in Fig. 3. Typical background values were: dissolved oxygen 8.6 mg/l light transmittance 1 to 2 percent, salinity 22 to 23 ppt, pH 8.2, and temperature 10.7 C. The dredge spoil field reached the survey vessel approximately two minutes after the horn signal and was accompanied with a reduction of salinity and temperature. Dissolved oxygen values fluctuated throughout the sampling period, and no change as a result of the dredge spoil was observed. Current speed during most of sampling period was slightly less than 1 knot, and direction ranged from north to north-northeast. No significant change to the current occurred as a result of passage of the field.

Releases 4, 5 and 6 occurred when the dredge was at a distance of 100 to 125 meters from the survey vessel. The current, which has been flooding during Releases 1, 2 and 3, reversed to ebb before Release 4 began.

The sensors of the water quality analyzer were near the bottom of the lower water mass for Release 4, and the data are in Fig. 3. Typical background values were: dissolved oxygen 8.3 mg/l near the end, light transmittance approximately 5 percent at the beginning decreasing to 1 percent, salinity 22.6 ppt, pH 8.2, and temperature 10.6 C. The dredge spoil field reached the survey vessel approximately three minutes and again seven minutes after the horn signal. Salinity and temperature values in the field were lower than background, but dissolved oxygen was slightly greater. Current speed during the sampling period was slightly less than 1 knot, and direction was toward the south-southwest. Current direction changed noticeably during passage of the dredge spoil field.

For Release 5, the monitoring level was near the center of the lower water mass, and background values at the beginning of the sampling period were: dissolved oxygen 8.9 mg/l, light transmittance 1 percent, salinity 17.8 ppt, pH 8.1 and temperature 10.4 C. Arrival of the dredge spoil field at the survey vessel was at two minutes after

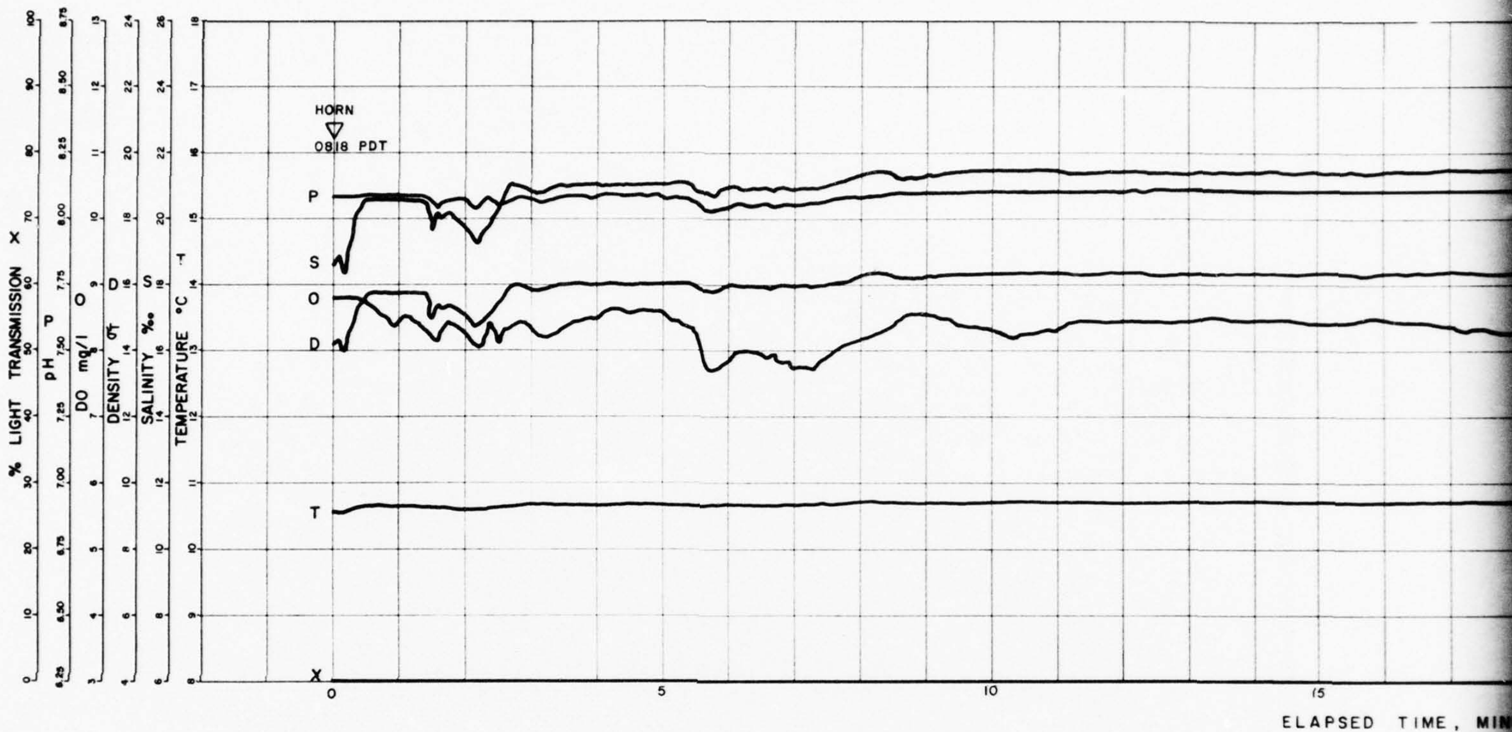
the horn signal and was accompanied with a slight increase in dissolved oxygen and decrease in salinity. Light transmittance was unchanged. Current speed at the beginning of the sampling period was slightly less than 1 knot toward the southeast. Measured current direction changed noticeably at two minutes after the horn signal.

The survey vessel's anchor began to drag during the sampling period of Release 5, and while indicated in Fig. 4 as beginning approximately nine minutes after the horn signal, the anchor may actually have begun to drag as early as two minutes after the horn signal. The sharp decrease in salinity at nine minutes shows that the survey vessel had moved into a different water mass. By twenty-five minutes after the horn, the survey vessel had dragged more than one mile from the station.

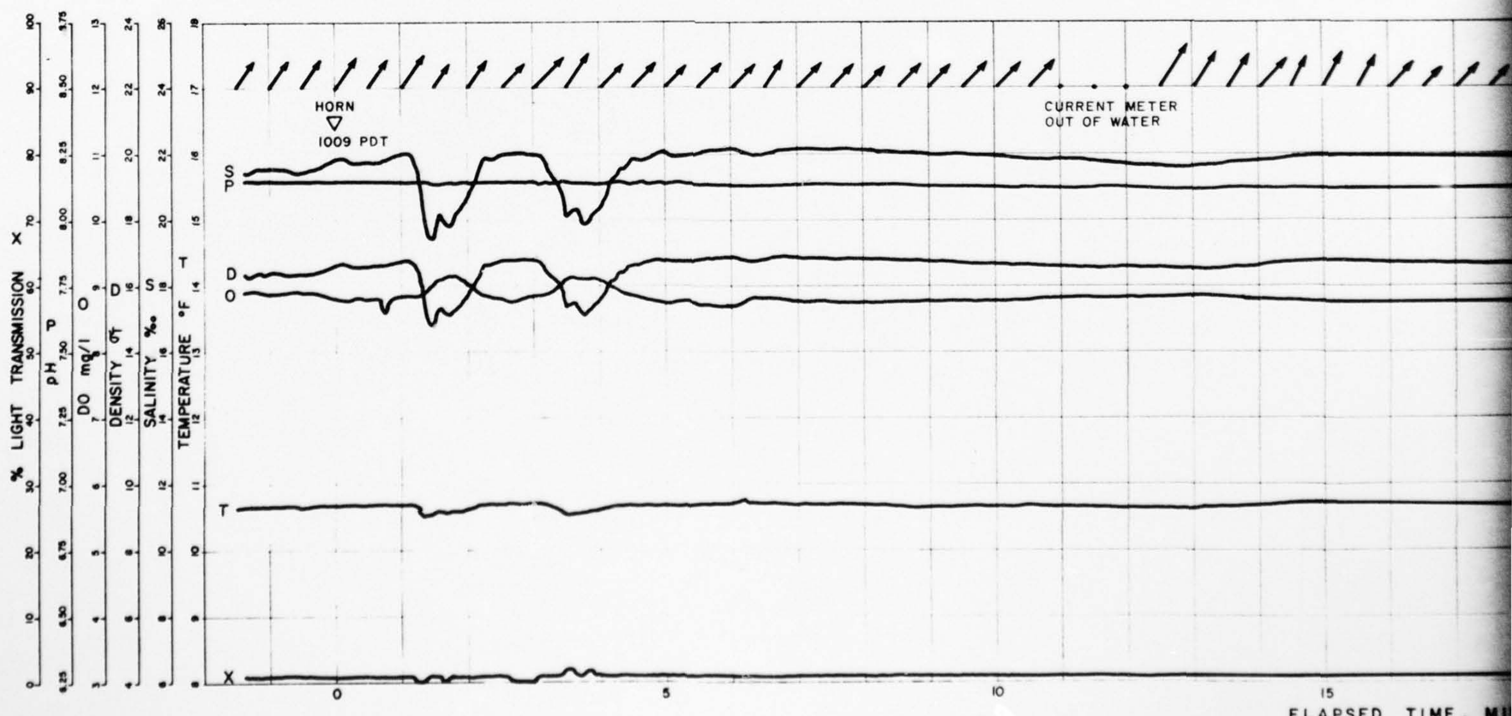
The upper water mass reached nearly to the bay bottom by the time of Release 6, so the monitoring level was located the same as during Release 5. As shown in Fig. 4, background values at the beginning of the sampling period were: dissolved oxygen 9.4 mg/l, light transmittance 1 percent, salinity 8.5 ppt, pH 8.0 and temperature 10.0 C. The dredge spoil field reached the survey vessel between two and three minutes after the horn and was accompanied by lower salinity and temperature values. Dissolved oxygen increased to nearly 10 mg/l and light transmittance was unchanged.

The survey vessel's anchor dragged during the entire sampling period because of the swift current, therefore, the current data recorded during Release 6 are omitted. The low values of dissolved oxygen shown following ten minutes after the horn signal are not related to the dredge spoil release, but instead may be due to a temporary malfunction of the dissolved oxygen sensor. The vertical profile obtained at 1741 hours, after Release 6 had ended, does not indicate dissolved oxygen values smaller than 9 mg/l.

The results of the monitoring survey indicate that the most significant initial effect of the dredge spoil disposal was the dilution of the spoil with entrained receiving water. The dredge released its cargo of dredge spoil approximately 15 feet beneath the surface, and as the spoil entered the receiving water, the accompanying turbulence caused surrounding water to be entrained into the dredge spoil field. Hence the water quality characteristics of the spoil were altered in proportion to the amount of receiving water entrained. The departures from background observed during passage of the dredge spoil field show the influence of this entrained receiving water.



% LIGHT TRANSMISSION X
pH P
DO mg/l O
DENSITY σt D
SALINITY ‰ S
TEMPERATURE °C T
HORN
0818 PDT
P
S
O
D
T
X
0
5
10
15
ELAPSED TIME, MIN



% LIGHT TRANSMISSION X
pH P
DO mg/l O
DENSITY σt D
SALINITY ‰ S
TEMPERATURE °F T
HORN
1009 PDT
CURRENT METER
OUT OF WATER
S
P
D
O
T
X
0
5
10
15
ELAPSED TIME, MI

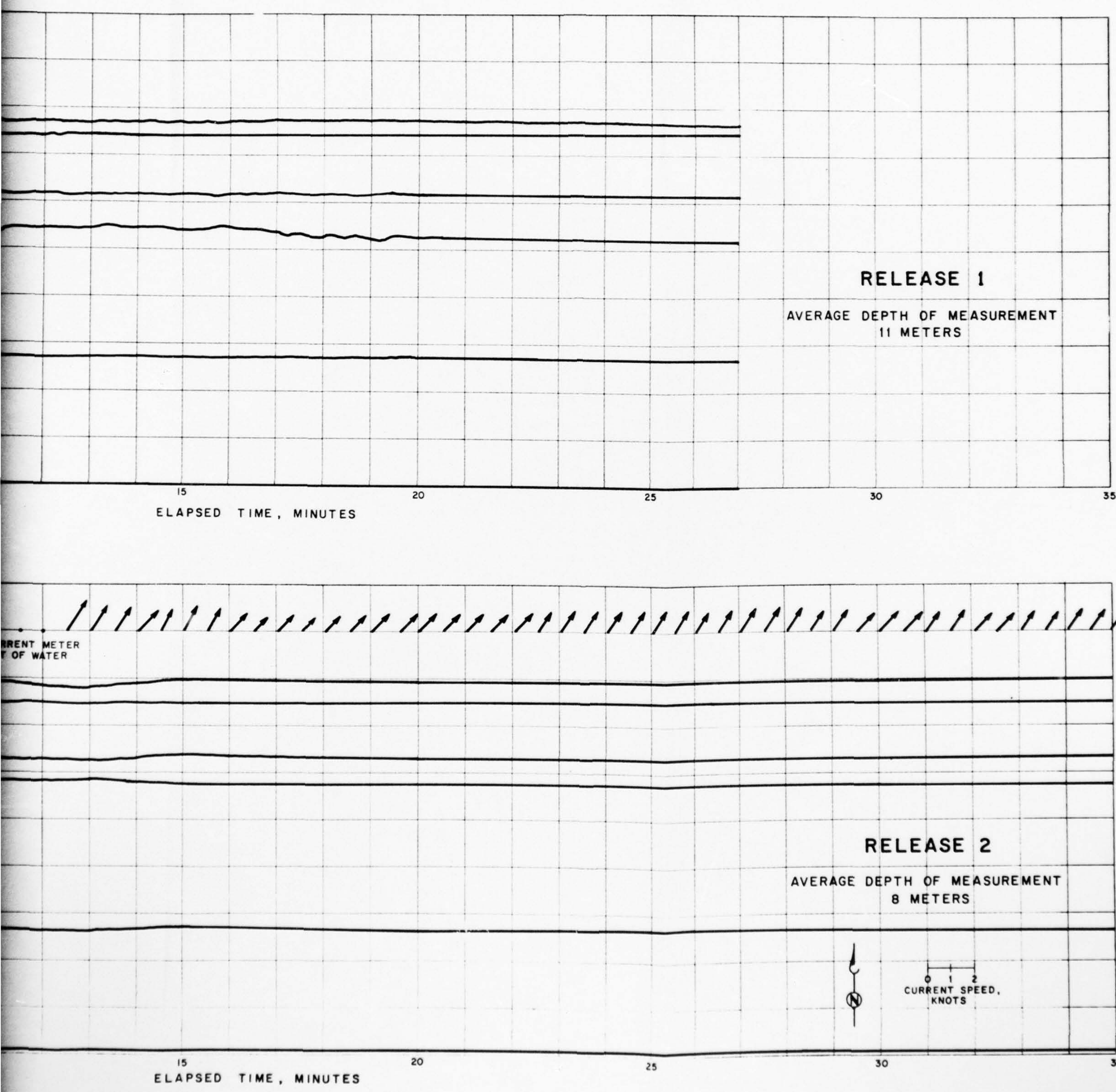
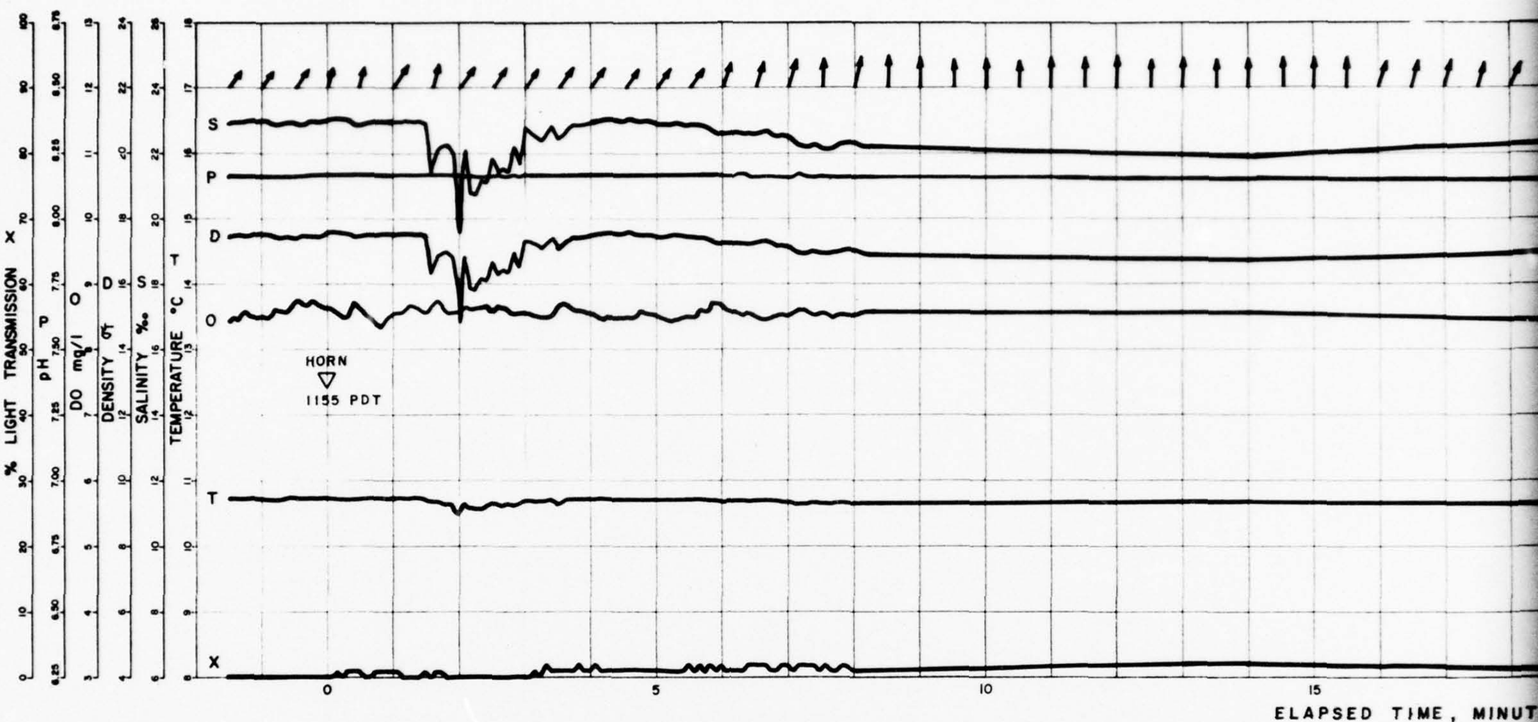
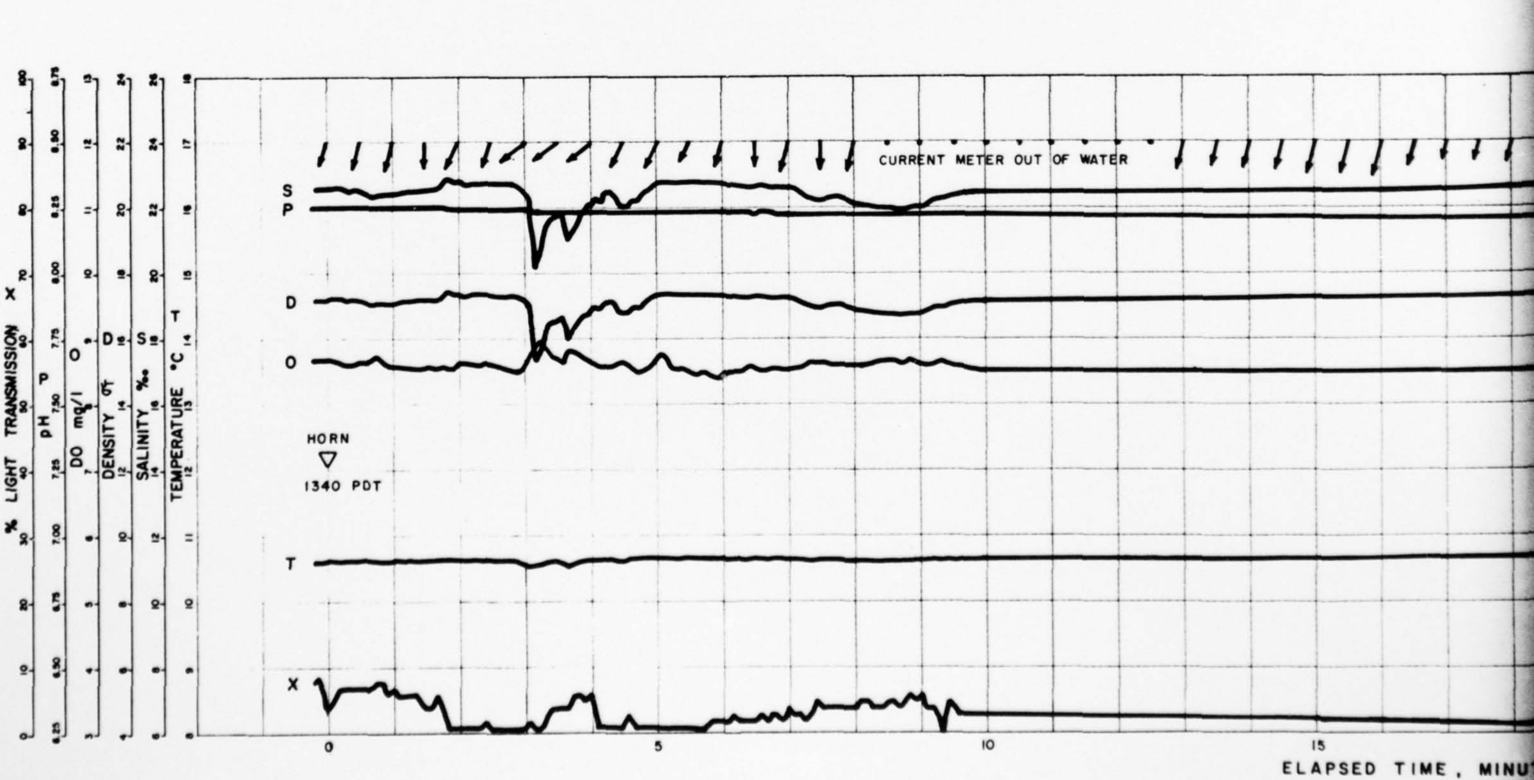
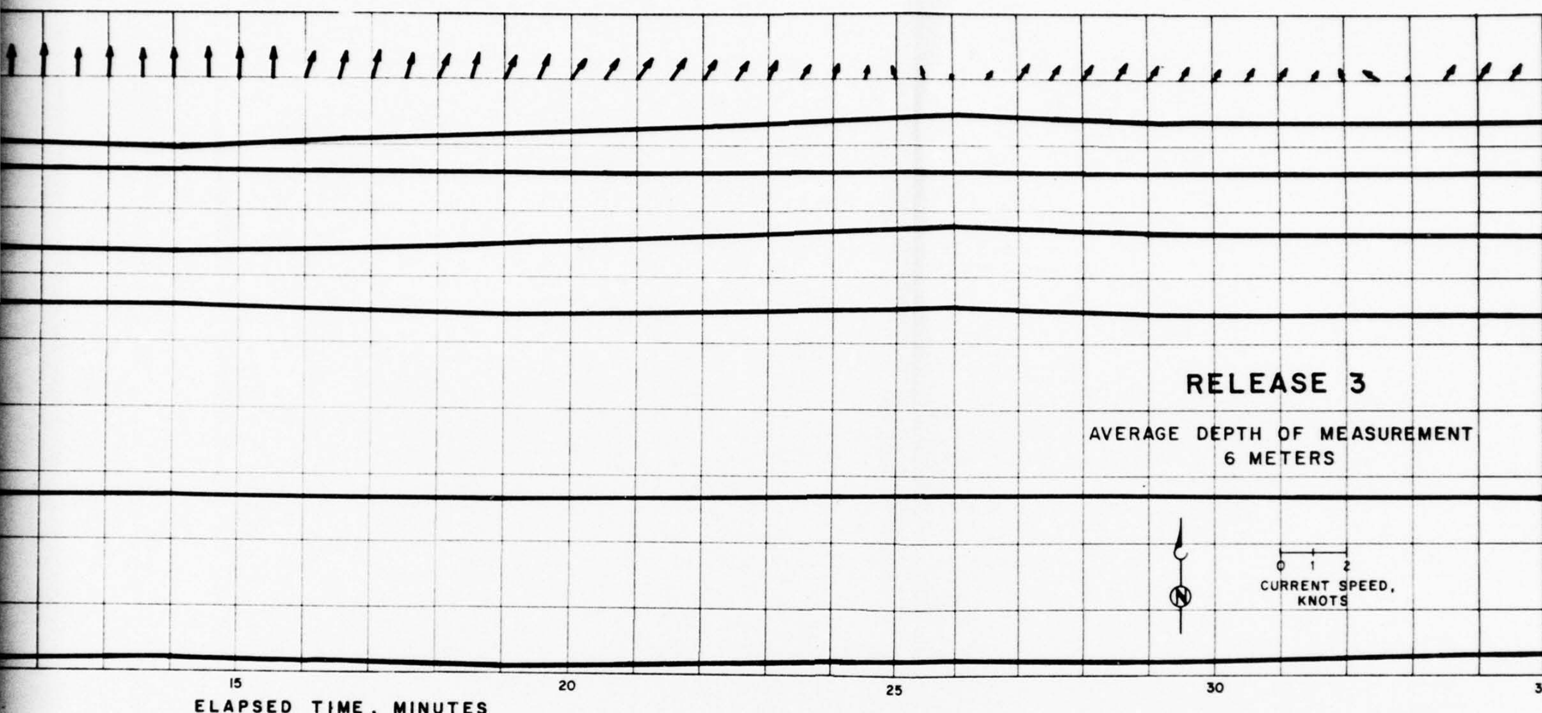


Fig. 2 Receiving Water Parameters
Releases 1 and 2

8


% LIGHT TRANSMISSION X
pH P
DO mg/l O
DENSITY σt D
SALINITY ‰ S
TEMPERATURE °C T
S
P
D
O
HORN
1155 PDT
T
X
0
5
10
15
ELAPSED TIME, MINUT


% LIGHT TRANSMISSION X
pH P
DO mg/l O
DENSITY σt D
SALINITY ‰ S
TEMPERATURE °C T
CURRENT METER OUT OF WATER
S
P
D
O
HORN
1340 PDT
T
X
0
5
10
15
ELAPSED TIME, MINUT



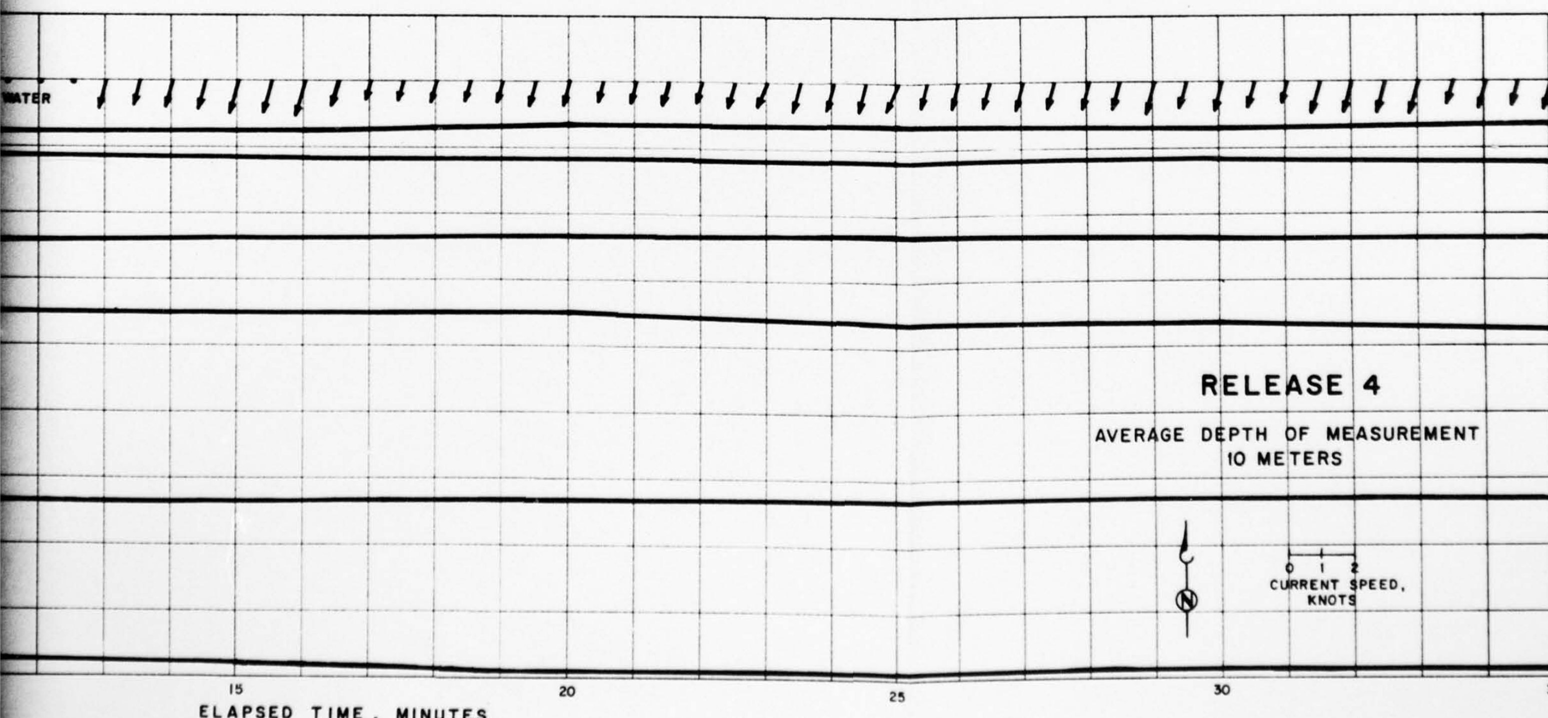
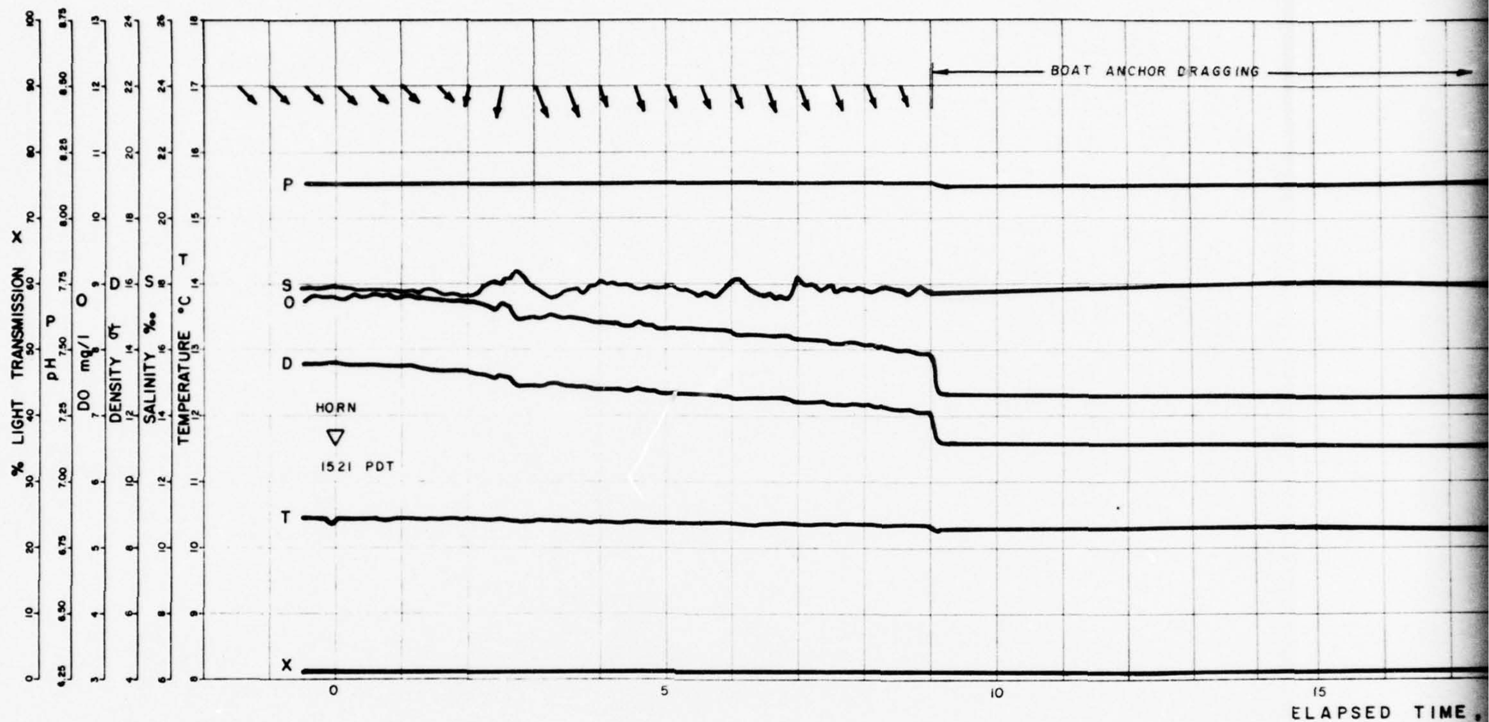
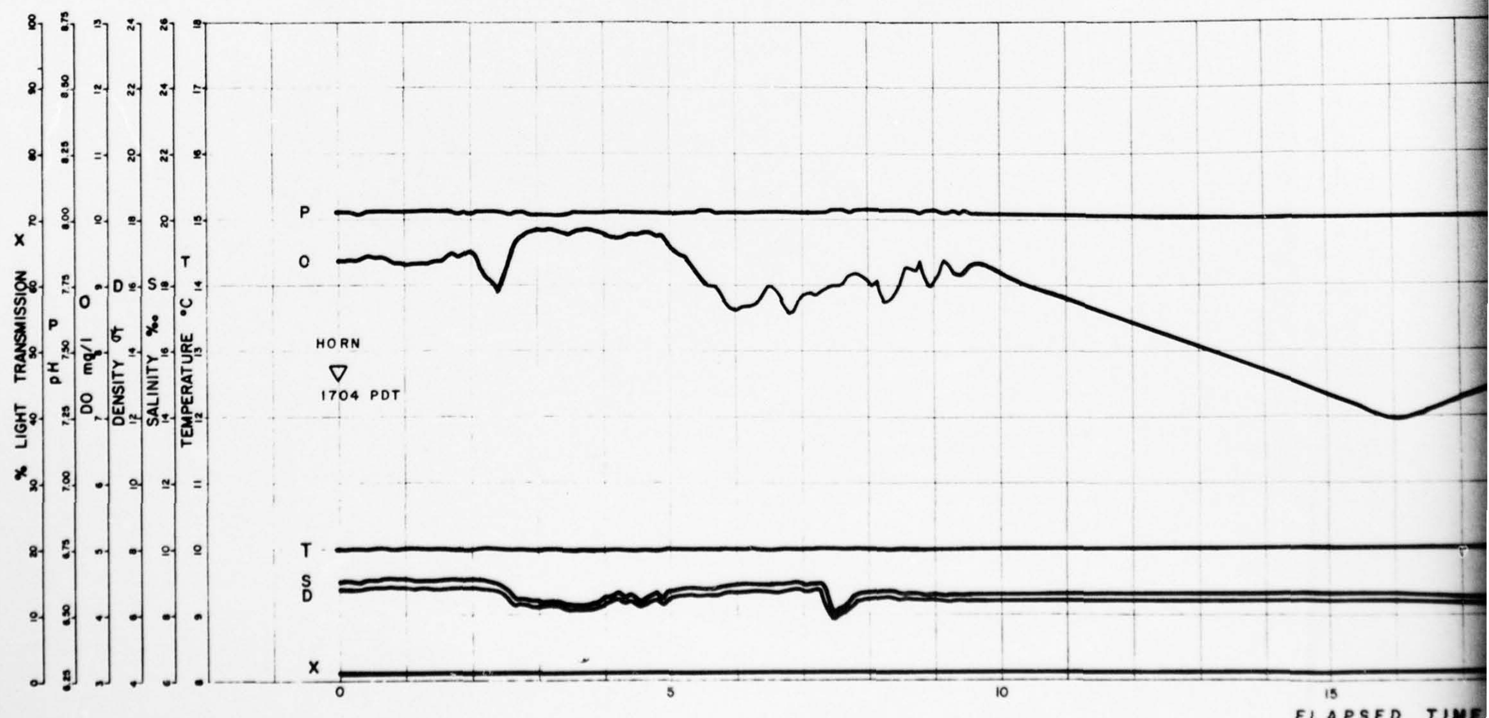


Fig. 3 Receiving Water Parameters
Releases 3 and 4


BOAT ANCHOR DRAGGING
P
S
O
D
T
X
HORN
1521 PDT
% LIGHT TRANSMISSION X
pH P
DO mg/l O
DENSITY σt D
SALINITY ‰ S
TEMPERATURE °C T
0
5
10
15
ELAPSED TIME,


P
O
T
S
D
X
HORN
1704 PDT
% LIGHT TRANSMISSION X
pH P
DO mg/l O
DENSITY σt D
SALINITY ‰ S
TEMPERATURE °C T
0
5
10
15
ELAPSED TIME

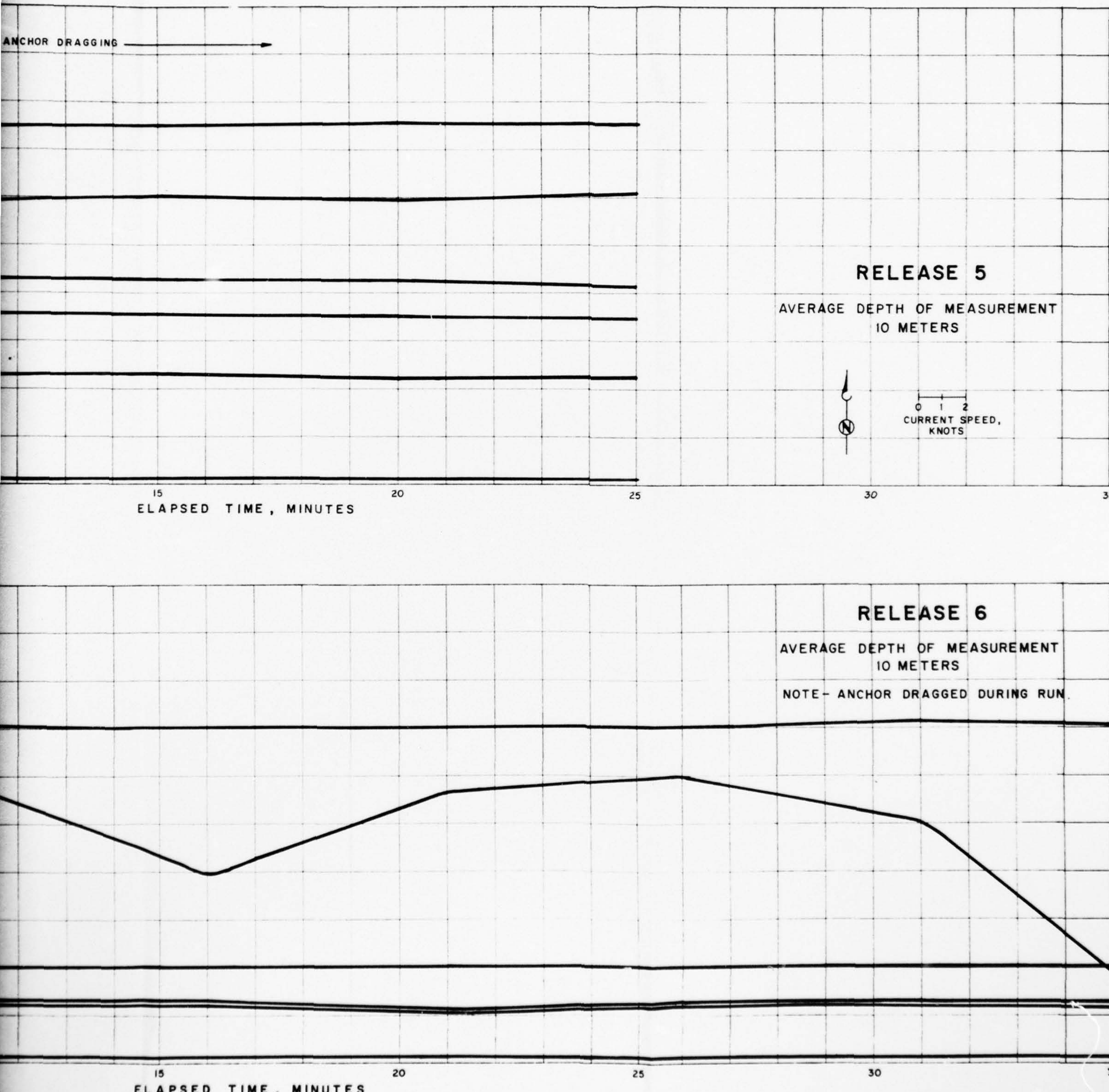
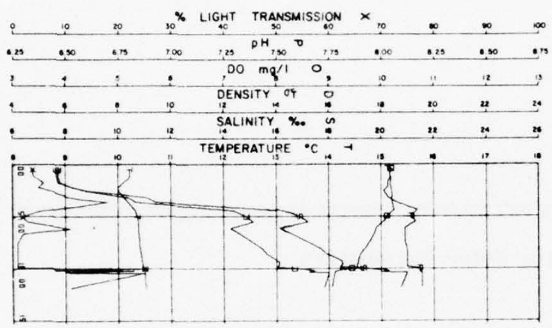


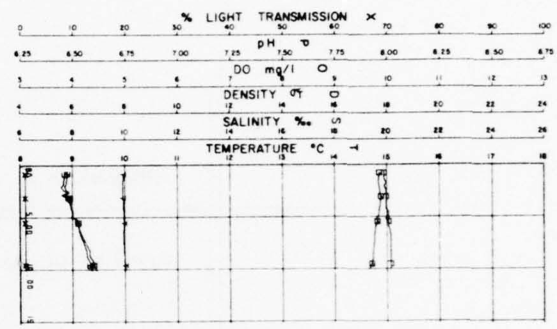
Fig. 4 Receiving Water Parameters Releases 5 and 6

APPENDIX A

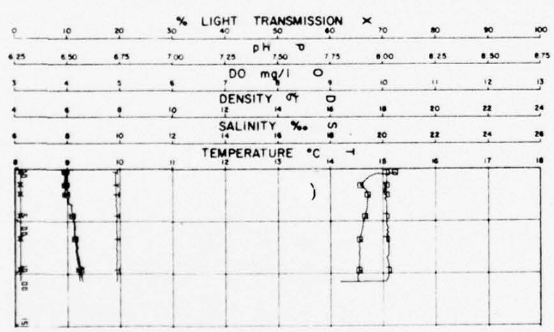
Profiles of Receiving Water Parameters



1509 PDT

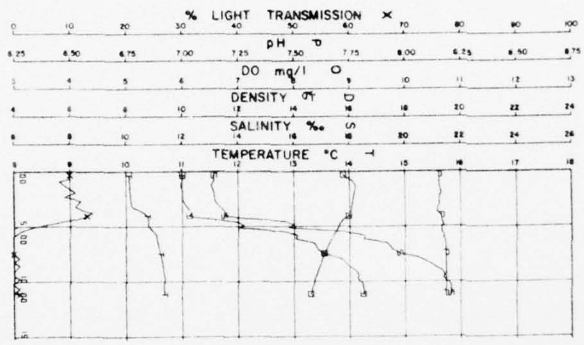


1700 PDT

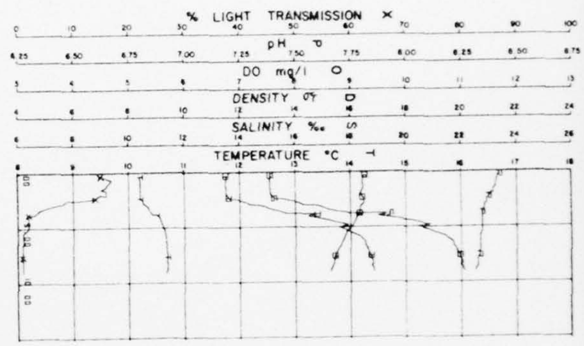


1741 PDT

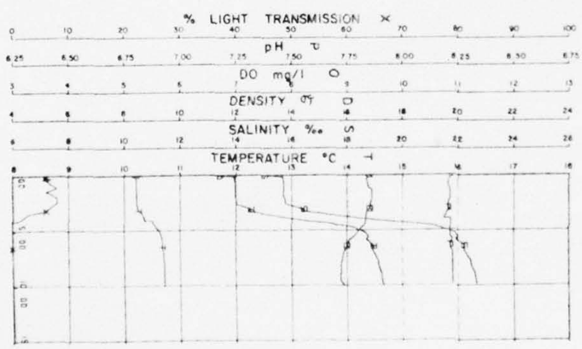
Plotted Profiles of Receiving Water Characteristics
Versus Depth in Meters



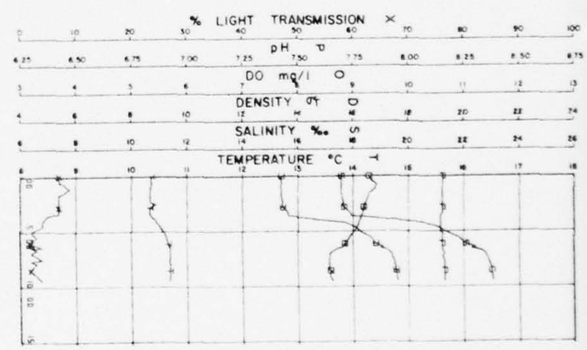
0958 PDT



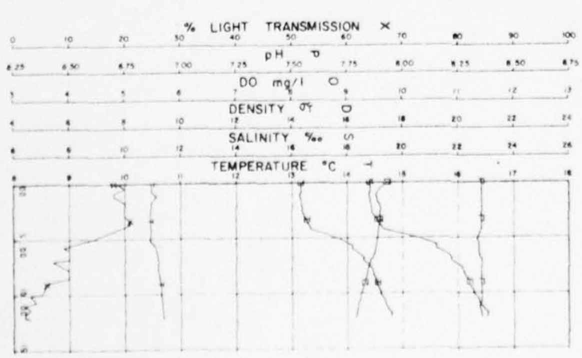
1048 PDT



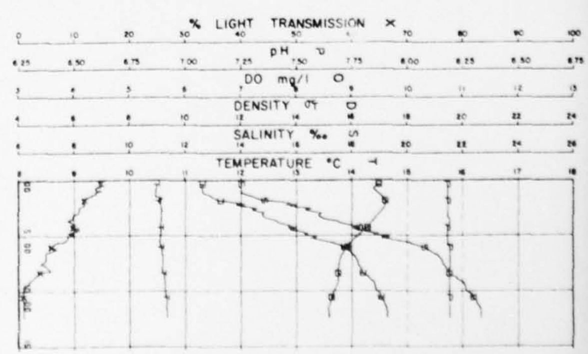
1136 PDT



1231 PDT



1330 PDT



1419 PDT